FIRE ECOLOGY AND NATIVE AMERICAN CULTURAL USE OF BEARGRASS (*XEROPHYLLUM TENAX* MELANTHIACEAE) IN THE PACIFIC NORTHWEST, U.S.A.

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This dissertation is dedicated to my mother, Siri Marion Jackman.

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ABSTRACT

Investigating biological and cultural conservation together provides the opportunity to characterize complex linkages between humans and nature. Understanding these human-nature interconnections within social-ecological systems is often essential in addressing environmental problems. Major goals of social-ecological research include describing the attributes of resilient systems and transitioning our globe towards them. The social-ecological systems of local and Indigenous Peoples can guide the development of resilience theory because these communities have persisted over hundreds of years to millennia and have in many cases survived the cataclysmic trauma of European colonization. Further, the traditional resource management systems of local and Indigenous Peoples often increase the abundance, diversity, reliability and/or quality of plant and animal resources. Here I explore possibilities to support both biological and cultural conservation under changing global conditions through a case study of an understory herb called beargrass (*Xerophyllum tenax* Melanthiaceae). Beargrass is well-suited to a social-ecological study as it has ecological, cultural and economic value. Beargrass has been traditionally managed through fire by Native Americans for millennia and is likely sensitive to fire suppression and other major drivers of change in the Pacific Northwest. To understand management needs and adaptive practices of Native American communities and to gather recommendations for biocultural revitalization of beargrass traditions, I interviewed beargrass weavers and cultural practitioners in Northern California, Oregon and southern Washington. To understand how plants may be responding to changes in management overtime, I conducted a plant demographic study. I collected field data over three years which was used to build mixed-effects regression models to understand the relationship of fire, leaf harvest and abiotic factors to beargrass survival, growth and reproduction. I then combined these regression models into integral projection models (IPMs) to understand how individual-level effects scaled up to the population level. I next used these IPMs to simulate stochastic beargrass population growth rates under different conditions. From the ethnographic study, I found that increasing access to beargrass leaves of appropriate quality for weaving and connecting Native American basket weavers with native youth were key opportunities for maintaining beargrass traditions, and that adaptive practices such as management substitutions in the absence of fire have helped maintain traditions over time. In the ecological study I found that beargrass growth and reproduction increased in response to fire, and that low intensity leaf harvest for cultural use reduced survival but increased vegetative reproduction. The fire scenario simulations revealed that re-introduction of traditional fire regimes (low severity fire every 1-20 years) led to population growth, while business as usual (high and low severity fire occurring every 180 years) and no fire both led to population decline. Leaf harvest slightly increased population growth in the traditional fire scenario due to increased vegetative reproduction. These results point to the key opportunities to support biocultural conservation through re-introduction of fire and cultural leaf harvest, restrictions on commercial harvest that reduce access, and education of the broader public on tribal sovereignty. Resilience of beargrass traditions appears tied to the deep spiritual and cultural importance of beargrass, its irreplaceability, the cultural values of respect and reciprocity embedded in beargrass traditions, and the ability to innovate management techniques in the absence of fire.

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Note on the study species name

In chapter two of the dissertation, I refer to the study species as “Bear Grass” because this was the preferred spelling and capitalization expressed by some weavers who contributed to that chapter. In other sections of the dissertation, I use “beargrass” for continuity with ecologically-focused peer-reviewed articles on *Xerophyllum tenax*.

Data accessibility

The three years of demographic and abiotic data, and the single year of leaf attribute data collected for this dissertation have been deposited at the Forest Service Research Archive.

Hart-Fredeluces, Georgia M.; Ticktin, Tamara B. 2019. Demographic and leaf attribute data for beargrass (Xerophyllum tenax Melanthiaceae) from Mount Hood National Forest, Oregon. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2019-0028

CHAPTER 1. BEARGRASS AS A CASE STUDY OF SOCIAL-ECOLOGICAL SYSTEMS

Rationale and broader context for the study

Addressing major environmental problems (e.g., invasive species, overfishing, wildfire risk, climate change) requires understanding the human dimensions of these issues (Cinner *et al.* 2009; McMillen *et al.* 2014; North *et al.* 2015). Cultural and social processes interact with environmental processes to produce linked social and environmental outcomes (Liu *et al.* 2007; Berkes 2012). Social-ecological research explores the interactions and synergies between environmental and social spheres of what are termed social-ecological systems (SESs) (Ostrom 2009). Examples of these systems include the Maine lobster fishery, small-scale agroforests in the Pacific, or even the entire globe when considering an issue such as climate change (Acheson 2003; Ticktin *et al.* 2018). The links between social and environmental spheres are complex (Azar, Holmberg & Lindgren 1996; Liu *et al.* 2007). Major research goals include understanding social-ecological systems dynamics, identifying indicators of change, and describing conditions that contribute to resilience (Azar *et al.* 1996; Fleischman *et al.* 2010; Ticktin *et al.* 2018). This dissertation explores interactions of ecological (plant demographic responses to disturbance) and sociocultural (access, sovereignty, reciprocity) aspects of indigenous gathering and use of an understory plant in the Pacific Northwest of the United States.

Wild plant harvest occurs across a diverse range of social-ecological systems. The ecological impacts of this harvest are complex and context dependent (Ticktin 2004). Non-timber forest products (NTFPs) include plants, fungi, lichens and other natural resources harvested from forests that are not sold as timber (Chamberlain, Emery & Patel-Weynand 2018). Examples include the harvest of herbs, bark and resins from forests for use as traditional medicine or for commercial sale as a livelihood option, the harvest of berries for ceremonial purposes or for food, and the harvest of palm fronds for weaving or thatching (Endress, Gorchov & Noble 2004; Ticktin & Shackleton 2011;

Turner, Deur & Mellott 2011a; Chamberlain *et al.* 2018). Ecological impacts of harvest depend upon multiple factors including plant part harvested, intensity of harvest, timing of harvest, life history stage of the plant, and the abiotic and ecological context (Mendoza, Piñnero & Sarukán 1987; Ticktin 2004; Gaoue & Ticktin 2010; Schmidt & Ticktin 2012). Harvest has variable effects on individual plants and populations. In some cases, plants compensate for tissue lost by increasing rates of photosynthesis or mobilizing stored reserves (McNaughton 1983; Oyama & Mendoza 1990; Anten, Martínez-Ramos & Ackerly 2003; Gowda & Raffaele 2004; Fang *et al.* 2008; Muola & Stenberg 2018). Reproductive output may increase with harvest (Baldauf *et al.* 2014), or decrease (Witkowski & Lamont 1996; Zuidema, De Kroon & Werger 2007; Mooney, Martin & Blessin 2015). Plant harvest also may have indirect effects, such as the compaction or aeration of soil, or the cutting of branches in the removal of fruits (Anderson & Rowney 1999; Sinha & Brault 2005; Turner *et al.* 2011a). Ancillary actions like thinning and transplanting that accompany harvest can also significantly impact plant population response to harvest (Ticktin & Johns 2002).

The social component of systems of wild plant harvest is equally diverse. Many NTFPs are culturally significant plants that have indispensable roles in local and indigenous communities, including in ceremony (Schultes & Hoffman 1979; Etkin 1988; Turner 2014). Culturally significant plants have often been tended, managed, and cared for in specific ways over generations and sometimes millennia (Ticktin & Johns 2002; Anderson 2005; Turner 2014; Vaughan 2018). Traditional ecological knowledge (TEK) is part of these systems of care and is defined by Berkes as: “a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with the environment” (2008, p7). This knowledge is integrated into Traditional Resource Management Systems that have been defined as: “the conscious accumulation, application, and adaptation of any combination of techniques and methods drawn from Traditional Ecological Knowledge (TEK) systems mediated by particular beliefs and worldviews, that sustain or enhance the availability, abundance, productivity, diversity, and/or quality of a plant or animal population or an entire resource area or habitat over a period of years or generations" (Turner 2014) (volume II, p148). Traditional resource management systems include ecosystem modification (e.g., burning, pruning, weeding, transplanting, and spreading seeds) and cultural expression (e.g., prayer and offerings before gathering, sharing with each other, traditional stories). The relationship of humans with each other and with the environment is understood in a moral and spiritual sense to involve the cultural values of respect, responsibility and reciprocity (Kimmerer 2002; Lepofsky 2009; Baldy 2013; Turner 2014; Vaughan 2018). For example, Giga'tat elder Helen Clifton recounts how: "all living things have their societies and families and you have to respect them..." (Turner 2005).

The knowledge and practices of traditional management systems can support biodiversity conservation in addition to sustaining cultural traditions (Trauernicht *et al.* 2015; Meyer 2017; Vaughan 2018). For local and indigenous communities, the practice of traditional lifeways are intimately tied to particular places and human-mediated ecological processes (Charnley, Fischer & Jones 2007; Norgaard 2014; Turner 2014). Many traditional management systems adapt natural disturbance regimes and successional processes in specific and complex ways to modify the abundance, distribution and quality of plant populations (Alcorn 1989; Anderson & Posey 1989; Berkes 2012; Turner 2014). For example, the Haustec in Northeastern Mexico have a *milpa* (swidden cornfield) system of shifting agriculture that takes advantage of successional processes to provide for desired species and to maintain a patchy mosaic of habitats (Alcorn 1989). This mosaic can increase habitat diversity, resilience and the reliability of resources for human needs.

Traditional knowledge and western knowledge may complement each other towards building an understanding of the response of plant life cycles to disturbance. Within the field of plant demography, the interaction of multiple drivers, such as management and climate factors are not well understood (Dalgleish *et al.* 2011; Ehrlén *et al.* 2016; Giljohann *et al.* 2017). This is particularly important in the context of global change, where multiple simultaneous factors may interact in non-linear and non-additive ways

(Brook, Sodhi & Bradshaw 2008; Souther & Mcgraw 2014). For example, the negative impacts of harvest on the mountain date palm (*Phoenix loureiri*) are reduced, not enhanced, when they co-occur with fire (Mandle & Ticktin 2012; Mandle, Ticktin & Zuidema 2015a). Traditional management systems are holistic and often long-term, suggesting strong potential to contribute to these gaps in understanding. Projects that can bridge worldviews and the trust barrier between local and indigenous communities and researchers are needed in order to honor this traditional knowledge and to build collaborations to address environmental challenges (Charnley, Long & Lake 2014; Hummel & Lake 2015; Long & Lake 2018). Supporting the revitalization of local and indigenous cultures through these collaborations requires an understanding of their contemporary resource management practices and needs, and recognition of the sovereign (equal to U.S. Federal government) status of tribal nations in decision making (Charnley *et al.* 2007; Nie & Nie 2008; Farley, Ellersick & Jasper 2015). This dissertation aims to contribute to this bridging effort, to highlight the voices of indigenous cultural practitioners and to help fill gaps in our understanding of complex plant responses to multiple drivers, and of characteristics of SESs that contribute to resilience.

Study system

Beargrass (*Xerophyllum tenax* (Pursh) Nutt. Melanthiaceae) is a fire-adapted liliaceous herb that occurs in the Pacific Northwest from British Columbia to Northern California and east into Montana (Crane 1990; Hummel, Foltz-Jordan & Polasky 2012). Beargrass is well suited to a social-ecological dynamics study as it is ecologically, culturally and economically important (Hummel *et al.* 2012). Beargrass is a fire-adapted species and has been subject to continuous traditional management by Native Americans in the Pacific Northwest, though less extensively today than in the past (Turner *et al.* 2011a; Lake & Long 2014). Beargrass has fibrous, durable and pliable leaves that are used in Native American weaving technologies including basketry and regalia (Hummel *et al.* 2012; Hummel & Lake 2015). Beargrass is also a multi-million US dollar non-timber forest product that became widely commercialized and sold in the floral greens industry beginning in the early 1990s (Thomas & Schumann 1993). Ecologically, beargrass provides food and/or nesting material for bears (*Ursus americanus and U. arctos*), elk (*Cervus canadensis* ssp. *rooseveltii* and *C. canadensis* spp. *nelsoni*), deer (*Odocoileus hemionus* and *O. virginianus*) and a variety of small mammals and insects (Hummel et al. 2012). From a tribal perspective, effective management for beargrass, including its availability and quality, requires meaningful access, the use of specific harvest techniques, and regular fire application (Anderson 2005; Shebitz, Reichard & Dunwiddie 2009b; Turner *et al.* 2011a; Hummel *et al.* 2012; Hummel & Lake 2015; Dobkins *et al.* 2016).

Cultural practitioners have reported that beargrass is becoming more difficult to find (Levy 2005; Shebitz 2005; Shebitz *et al.* 2009b, this dissertation) and beargrass has decreased in range and local abundance in some regions, likely due to fire suppression (Peter & Shebitz 2006; Shebitz, Reichard & Woubneh 2008). The issue is not only quantity of plants, but quality (Shebitz 2005). Weavers have varying preferences for leaf quality, but long, slender, thin, strong, pliable, blue-green hued and light-colored leaves, particularly those which are promoted by recent fire, are preferred in some regions (O'Neale 1932; Peter & Shebitz 2006; Lake 2007; Hummel & Lake 2015), but are increasingly hard to find. Maintaining access and relationship to places where beargrass can be acquired is important to several tribes in Oregon (Dobkins *et al.* 2016). The best quality beargrass for basketry is reported to be from plants in partial shade that have resprouted after a low or moderate intensity fire (O'Neale 1932; Nordquist & Nordquist 1983; Shebitz 2005; Lake 2007). Harvest often occurs within one to several years after the fire (Hummel *et al.* 2012; Baldy 2013; Hooper 2015).

Harvest practices include giving thanks, never taking an entire plant, gathering with a purpose (Baldy 2013), not taking more than you need (Hummel *et al.* 2012), and, in some areas, avoiding the center leaf whorl or "heart" of the plant (Hooper 2015). Leaf harvest impact on the populations is generally spread out by only gathering from a small subset of plants (e.g., one gatherer says no more than 20% of plants in an area, cited in Baldy 2013), and taking only a few leaves per plant (e.g., taking up to 15 leaves on the larger plants that would have over 100 leaves, Hooper 2015, p182). Harvest is typically by pulling a few leaves at a time (Anderson 2005), from plants that have reached full maturity (Hummel *et al.* 2012). Beargrass is difficult, but not impossible, to cultivate and/or transplant (Hummel *et al.* 2012). The vast majority of subsistence and commercial leaves are wild-harvested.

Native American fire stewardship was and continues to be important for maintaining beargrass populations of desired leaf quality (Peter & Shebitz 2006; Turner *et al.* 2011a; Hummel *et al.* 2012; Lake & Long 2014). Native Peoples in the Pacific Northwest of North America employed fire in diverse ways for diverse purposes (Lewis 1982; Williams 2000; Wray & Anderson 2003; Anderson 2005; Lepofsky 2009; Lake & Long 2014; LeCompte-Mastenbrook 2015). Fire was used to open sites for edible camas (*Camassia quamash*) populations, to improve high elevation huckleberry (*Vaccinium* spp.) picking areas, to improve hunting grounds, and to produce materials for basketry and other arts and technologies (Boyd 1999; French 1999; Kimmerer & Lake 2001; Wray & Anderson 2003; Turner *et al.* 2011b). The state and federal policies of fire suppression and exclusion, fully implemented by the mid 20th century, in combination with genocide, forced relocation and disease epidemics that accompanied European colonization, effectively removed Native American fire from the landscape (Kimmerer & Lake 2001; Hessl, McKenzie & Schellhaas 2004; Hatfield 2009; Trosper *et al.* 2012a; Walsh, Duke & Haydon 2018). Without fire, some forest openings and prairies have experienced an increase in the density of early successional trees (Wray and Anderson 2003, Christy and Alverson 2011, Peter and Harrington 2014). Some plant species, adapted to particular fire regimes, including fires set by Native Peoples, are now less common. Examples include the endangered Bradshaw's lomatium (*Lomatium bradshawii*), huckleberries (*Vaccinium* spp.), camas (*Camassia* spp.), tobacco (*Nicotiana* spp.) and deergrass (*Muhlenbergia rigens*) (Anderson 1996; Boyd 1999; Kaye *et al.* 2001).

This study draws upon and acknowledges the existence and value of Traditional Ecological Knowledge and Traditional Resource Management systems of Native Peoples of the Pacific Northwest who have successfully and sustainably managed beargrass and forested ecosystems for thousands of years. Today, climate change, fire suppression, invasive species, access issues, and other aspects of contemporary forest management, have altered the ecological, social, political, educational and economic landscape where this knowledge is practiced and taught. By measuring and collecting ecological and ethnographic data, this project aims to provide insights that can support the conservation of biological diversity of forested ecosystems and associated Indigenous biocultural practices in Oregon and the Pacific Northwest, while upholding the sovereignty of Native Peoples (sovereignty refers to recognizing the inherent authority of indigenous tribes to govern themselves within the borders of the United States and the formal nation-to-nation relationship tribes have with the US government), and protecting the privacy and intellectual capital of individuals and Nations.

Research goals

Long-term and applied goals

- Identifying research processes and themes that will facilitate collaboration between ecological science and indigenous stewardship with the goal to strengthen cultural traditions and to enhance ecological integrity
- Increase the visibility of indigenous cultural values and needs in land stewardship

Chapter-specific objectives

Ch. 2. Identify the main challenges, adaptive practices and recommendations of Native American cultural practitioners for the revitalization of beargrass traditions.

Ch. 3. Describe how fire, leaf harvest and abiotic factors influence beargrass survival, growth and reproduction in a contemporary forest context.

Ch. 4. Using simulations, show how contemporary forest management conditions are projected to influence beargrass population persistence into the future.

Ch. 5. Synthesize findings across previous chapters, focusing on contributions to ecological and social-ecological theory.

Overview of chapters

The second chapter reports on contemporary Native American stewardship practices for beargrass, with a focus on challenges, adaptations and recommendations of Native American weavers and cultural practitioners for the revitalization of beargrass traditions. This second chapter is based on the author's experiences and participation in projects, gatherings, and meetings over more than seven years in the Pacific Northwest with an emphasis on Oregon, as well as on semi-structured interviews with seven weavers. The second chapter helped identify social and cultural aspects of resilience of the overall social-ecological system and provided recommendations for strengthening cultural traditions. It also helped define feasible contemporary management scenarios to test in the simulations in chapter four and helped build a context to interpret findings in chapters three and four. While the second chapter emphasizes resilience of cultural traditions through change, the third chapter focuses on beargrass demography and the relationship of plant survival, growth and reproduction to changing fire regimes, leaf harvest and abiotic conditions. The findings presented in chapter three are based on three years of field data collected in plots across three sites that experienced wildfires. Plots were placed in areas of different fire severity (high severity, low severity and unburned). The fourth chapter then evaluates how identified changes in individual vital rates (survival, growth and reproduction) scale up to the population level to determine long-term growth rates of beargrass populations under different fire regimes, with and without leaf harvest for cultural use. The models for the fourth chapter are integral projection models built from the mixed-effects regression models presented in chapter three. Stochastic long-term population growth rates are simulated using Markov Chain Monte Carlo methods and fire return intervals are determined stochastically from Weibull functions. The results of the simulations are then analyzed with stochastic life table response experiments (STLREs) in order to identify the contributions of the plant life cycle stages, the stochastic sequence of events, and particular years or environments to the overall findings. The conclusion chapter (chapter five) synthesizes findings across these chapters to provide steps forward for the revitalization of beargrass cultural traditions in Native American communities, including recommendations to support the persistence of plant populations of the quality needed for cultural and ecological ecosystem services. It also identifies lessons from this study that may be helpful for people working towards biocultural revitalization in other places.

CHAPTER 2. IN THE WORDS OF WEAVERS: ADAPTIVE PRACTICES AND THE RECOMMENDATIONS OF NATIVE AMERICAN BASKET MAKERS FOR BIOCULTURAL CONSERVATION OF BEAR GRASS (*XEROPHYLLUM TENAX* MELANTHIACEAE)

Abstract

Social-ecological systems (SESs) research explores complex linkages between people and nature. This type of research can provide valuable insights for addressing complex environmental problems. One goal of SESs research is to identify the characteristics of resilient resource use systems. The SESs of local and Indigenous Peoples have often persisted through major social and ecological changes (e.g., colonialism) and therefore have strong potential to contribute to SESs resilience theory. However, in order to learn from local and Indigenous cultural practitioners and resource management leaders, a researcher needs to build trust with individuals and make space for local and Indigenous voices to be heard. In this chapter, I report on my experiences with this process and share the knowledge and recommendations of cultural practitioners for the revitalization of Bear Grass traditions in the Pacific Northwest, U.S.A. Here I ask: (1) What are the key cultural practices and protocols associated with Bear Grass traditions today? (2) How have the abundance, quality and access to of Bear Grass changed over time and what are the reasons for these changes? (3) What are the adaptive strategies that tribal communities in the Pacific Northwest use to maintain cultural traditions in the face of social and ecological change? (4) What are the broader recommendations of weavers for strengthening biocultural connections to Bear Grass? Participation in programs and meetings, as well as semi-structured interviews with seven cultural practitioners revealed multiple reciprocal practices between Native American communities and Bear Grass plants. Decline in abundance and quality of Bear Grass was also reported. Spatial shifts and management substitutions, though not direct substitution of other materials for Bear Grass, were effective adaptations to maintain

Bear Grass traditions through changing conditions. Interviewees recommended restrictions on commercial harvest and greater collaboration and/or sovereign control over resource management to promote Bear Grass persistence and quality, particularly with regard to the use of fire. Increasing the connection and access of tribal community members to nature and to Native American weaving teachers was also recommended. Overall, resilience in this social-ecological system from a social-cultural perspective is likely driven by the deep spiritual and cultural importance of beargrass, its irreplaceability, the cultural values of respect and reciprocity embedded in beargrass traditions, and the ability to innovate alternative management practices in the absence of fire.

Introduction

Local and indigenous peoples' traditional management systems shaped and continue to shape natural ecosystems (Berkes *et al.* 1989; Turner 1999; Trauernicht *et al.* 2015; Meyer 2017; Vaughan 2018). These social-ecological systems (SESs) have persisted through drastic and traumatic changes (Hatfield 2009; Norgaard 2014; Long & Lake 2018). Lessons from their resilience can therefore contribute to resource management as well as theoretical understanding of the characteristics that confer resilience in resource use systems (Walker *et al.* 2004; Folke *et al.* 2010; Kramer *et al.* 2017). However, the knowledge and needs of indigenous peoples are not always considered when decisions are made about natural and cultural resources in their ancestral territories (Turner *et al.* 2008; Middleton 2010). For local and indigenous communities with little or no land base, this restricts the practice of traditional lifeways which are intimately tied to particular places and human-mediated ecological processes (Charnley *et al.* 2007; Norgaard 2014; Turner 2014). Tribal Nations in the United States are sovereign entities with government-to-government relationships to the U.S. Federal Government. Tribal reserved rights include cultural practices such as fishing, hunting and plant gathering (Farley *et al.* 2015). These rights, however, are not always honored (Dobkins *et al.* 2016; Teodoro, Haider & Switzer 2018). Supporting the revitalization of tribal cultures requires an understanding of contemporary tribal resource management practices and needs and acknowledgement of tribal sovereignty and Federal-Tribal

Trust Responsibilities in natural resource decision-making (Charnley *et al.* 2007; Nie & Nie 2008; Farley *et al.* 2015). Including the voices of indigenous leaders and cultural practitioners in the discussion and planning for natural and cultural resource management is a key part of this process.

In this paper I discuss the knowledge and recommendations of indigenous cultural practitioners for the resilience and revitalization of Bear Grass (*Xerophyllum tenax* Melanthiaceae) traditions through changing conditions. Bear Grass is a wild-gathered plant used in a wide range of weaving technologies by Native Americans in the Pacific Northwest of the United States (Figs 2.1 and 2.2) (Hummel *et al.* 2012; Baldy 2013). While the plant is not considered rare or threatened from a biological perspective, it is locally reported to be difficult to access (O'Neale 1932; Levy 2005; Shebitz *et al.* 2009b; Hummel & Lake 2015; Dobkins *et al.* 2016). Further, the Native American cultural practices associated with Bear Grass and other plants are less common today than in the past (Hummel *et al.* 2012; Long & Lake 2018). Bear Grass is a plant with a deep cultural importance, whose roles in Native American communities have persisted through colonization, genocide, removal to reservations and other societal changes over time in the Pacific Northwest (O'Neale 1932; Hatfield 2009; Trosper *et al.* 2012a; Baldy 2013). I report on findings from participation in community gatherings, from learning to weave, and from conducting semi-structured interviews focused on the care, use and management of Bear Grass today. The recommendations of cultural practitioners from these interviews highlight the multiple values of Bear Grass traditions, the diversity of needs across tribal communities, and the importance of understanding and supporting local tribal natural and cultural resources needs in stewardship projects.

The topic of Bear Grass and traditional knowledge has been explored by other researchers. It receives mention or short descriptions in ethnographic and ethnobotanical works covering the region of the plants' range from Northern California to British Columbia, and east into Montana. Texts specific to basketry such as O'Neale (1932) and Nordquist and Nordquist (1983) describe the care, gathering, preparation and use of Bear Grass in weaving traditions among specific Tribal Nations. Suttles, in the Handbook of North American Indians, provides images and descriptions of Bear Grass' importance in what is termed the Northwest Coast Region (Suttles 1990). More recently, Daniela Shebitz's work described weavers' recollections of traditional fire stewardship for Bear Grass on the Olympic Peninsula, measured the decline in Bear Grass over time with fire exclusion, and described the sacred role of Bear Grass in indigenous lifeways and maintenance of cultural traditions (Shebitz 2005; Peter & Shebitz 2006). Kat Anderson reports on historical accounts of Bear Grass burning, as well as contemporary use, care and management of Bear Grass in California (Anderson 2005). Frank Lake's work in Northern California details issues of stewardship, access, fire ecology and weaving technologies surrounding Bear Grass (Lake 2007; Lake & Long 2014; Hummel & Lake 2015). Susan Hummel and David Peter have also contributed extensively to our understanding of both Bear Grass ecology and cultural use (Hummel *et al.* 2012; Peter, Harrington & Thompson 2017). This paper builds upon this previous work, with an emphasis on adaptive practices and recommendations of cultural practitioners for the maintenance and revitalization of Bear Grass biocultural traditions under changing conditions.

In chapters three and four, I discuss the impacts of fire, soil moisture, light and cultural harvest on Bear Grass. In those studies, I found that that fire management and leaf harvest, as practiced by Native American communities, both increased Bear Grass population growth. Researchers before me also demonstrated positive impacts of fire and light on Bear Grass reproduction (Shebitz *et al.* 2008; Shebitz, Ewing & Gutierrez 2009a; Shebitz *et al.* 2009b; Peter *et al.* 2017). In addition to its traditional uses, Bear Grass is wild-gathered for the floral greens industry and has been illegally poached on tribal lands and removed in mass quantities from public lands with minimal regulation or understanding of the ecological effects of this commercial harvest (Thomas & Schumann 1993; Vance, Bernhardt & Edens 2004; Hooper 2015). Bear Grass has incredible floral displays that attract visitors to particular hiking trails, and it provides food, habitat and/or nesting material for animals from insects to grizzly bears (Hummel *et al.* 2012) (Fig 2.3). Bear Grass is a plant that benefits from fire, and thus has been impacted by the suppression of wildfire, and the exclusion and criminalization of Native American fire stewardship (O'Neale 1932; Crane 1990).

Bear Grass is reported to be declining in parts of its range due to commercial leaf harvest for the floral greens industry (Fig 2.4) and the suppression and exclusion of fire (Levy 2005; Peter & Shebitz 2006; Shebitz *et al.* 2008, 2009b). The issue is not only the abundance of the plant, but also changes in leaf characteristics that result from changing fire regimes. In the absence of traditional fire management, leaf qualities desired for weaving by many weavers, such as long, supple leaves, are becoming more difficult to find (Rentz 2003; Levy 2005; Shebitz *et al.* 2009b; Hummel & Lake 2015). Further, insufficient access to quality leaves has also been reported as a result of permitting processes, road closures and lack of time and/or financial resources for gathering trips (Dobkins *et al.* 2016). In some areas, there is also concern that there are very few weavers using Bear Grass (pers. comm., Tribal Culture and Heritage Committee, Oregon, 2017). In this chapter, I therefore explore options to support three related goals: increasing the abundance and accessibility of Bear Grass, increasing the quality of Bear Grass, and increasing the number of tribal community members who practice cultural traditions associated with Bear Grass, including traditional fire management, plant care and gathering, and weaving technologies.

This chapter aims to contribute to an understanding of how local and indigenous cultural practices can be supported and strengthened in contemporary times, and to help build theoretical understanding of characteristics that contribute to resilience in social-ecological systems. My specific research questions were as follows: (1) What are the key cultural practices and protocols associated with Bear Grass traditions today? (2) How have the abundance, quality and access to of Bear Grass changed over time and what are the reasons for these changes? (3) What are the adaptive strategies that tribal communities in the Pacific Northwest use to maintain cultural traditions in the face of social and ecological change? (4) What are the broader recommendations of weavers for strengthening biocultural connections to Bear Grass?

Methods

I connected with weavers through multiple avenues including attending weaving or community gatherings to meet people and to ask for recommendations of other weavers who I could contact. I also called or emailed weavers directly after web searches. I advertised the project through newsletters and social media, and received leads from tribal council members and resource managers about weavers I could contact. I attended the Northwest Native American Basket Weavers Association annual basketry gathering and the Intertribal Timber Council's annual meeting in 2015 allowing me to connect with weavers and resource managers in person, facilitating later meetings and conversations. Two of the weavers in this project were also my weaving teachers (Fig 2.5). I was educated about values and needs of Native American communities more broadly as a co-developer of a culturally-tailored curriculum (2013-2016) at a Native American non-profit in Portland, Oregon called Wisdom of the Elders, Inc. Further, I also organized a short educational program in 2015 with the help of Warm Springs museum staff for the Warm Springs alternative high school on traditional plant uses, including basketry. This involved connecting Native American teachers and elders with Native American high school students for hands-on and outdoor activities. Basketry was a favorite activity. I also met several times with the Warm Springs Culture and Heritage Committee and once with the Education Committee, as well as with the director of Natural Resources and other leaders to discuss project possibilities. Two Native American youth (daughters of a Bear Grass weaver) worked as field assistants on the ecological project conducted on Mount Hood. These interactions were rich and informative. Some of the key data for this paper comes not from interviews, but from conversations, observations, learning from youth, and learning from tribal collaborators.

Past and continuing abuses of Native American communities by researchers and the broader uninformed public in the Pacific Northwest meant that collaboration in research was sensitive territory, and that trust building was a slow and thorny process (Smith 2013; Hummel & Lake 2015). In addition, other community concerns, including safety and financial security, sometimes superseded interest in spending time of this kind of project. Further, in some communities, Bear Grass is no longer well known or utilized.

One member of a tribal community estimated that only two families on the reservation still used this plant. For that community, I was told there was plenty of Bear Grass, but not enough weavers. For this, and the previously mentioned reasons, identifying and getting to know weavers for this study was not a simple process. I therefore decided to broaden the target community for the study to the Pacific Northwest region in order to increase the pool of potential Native American weavers, and to explore some of the variability in care, gathering, preparation, and use of Bear Grass, as well as variation in the stage of cultural revitalization of Bear Grass traditions within different tribal communities.

This study draws upon experiences described above, my process of learning to weave with Bear Grass, and upon semi-structured interviews completed in 2017 and 2018 with seven individuals: six Native American weavers and one non-Native spouse of a Native American weaver who all utilize Bear Grass and are considered experts or leaders in their community for their cultural knowledge and/or skills. Weavers interviewed lived in Northern California, Oregon or the Olympic Peninsula of Washington State and were members of The Confederated Tribes of the Coos, Lower Umpqua and Siuslaw Indians of Oregon, The Confederated Tribes of Siletz Indians of Oregon, The Makah Tribe, The Tuscarora Nation, of Cherokee ancestry or descendants of the Karuk Tribe. The Tuscarora and Cherokee Nations are located in the eastern United States. The weavers of these tribal affiliations or of these ancestries have lived for decades in the Pacific Northwest and have learned to weave with Bear Grass from Native American weavers who are members of tribes in the Pacific Northwest. Though most forms of weaving were historically practiced by women (O'Neale 1932; Nordquist & Nordquist 1983; Suttles 1990), in this study four weavers were women and three were men. The interview process involved prior informed consent through signature for the interview and for the audio recording (University of Hawai'i at Mānoa, IRB Human Studies, CHS 23677). Interviews ranged from 50 minutes to 2.5 hours. They were fully transcribed and returned to interviewees for their records and to correct errors. Each interview was then coded in Microsoft Word by separating (or duplicating) interviewee statements into rows of a table and placing codes in the column to the left of each statement and producing memos from codes to guide development of major themes (Glaser 1978; Hahn 2008; Charmaz 2014). More specifically, statements were assigned short codes based on overlap with research questions or as emerging themes (e.g., “Following proper gathering protocol”, “sharing Bear Grass leaves”, “generational passing knowledge”, “fire effects on Bear Grass”, “microsite gathering decisions”, “management substitutions”). Similar codes that were common across interviews were merged into a shorter secondary set of codes. These codes were further coalesced to identify themes presented here. Here I discuss themes that were addressed by the majority of interviewees, unless otherwise noted. Exceptions were made for topics that have not been previously published, or which were clearly of deep importance to a given interviewee.

Results

The main findings for this chapter were that Bear Grass traditions reinforce identity and cultural values, that the abundance and leaf quality are reported to be declining for most weavers, that adaptive practices of Native Peoples help maintain cultural traditions, and that Bear Grass cultural traditions can be supported through education, collaboration, improved access and greater recognition of tribal sovereignty (Table 2.1).

Part I: Maintaining identity, harmony and balance with the environment and with each other through the care and gathering of Bear Grass

Sometimes a tree or plant are not ready to be harvested. You’ll kinda know. They’ll guide you and they’ll tell you when to stop harvesting. Elaine Rice St. Martin (Tuscarora/Seneca)

A basket begins well before the weaving with the observing and tending of the plant and its environment. Tending and gathering are also spiritual practices that reinforce Native American identity. Practices include prayer, giving an offering, following proper leaf harvest technique, only taking what you need, consideration of elders, and sharing with each other. These practices strengthen social ties within tribal communities. They also strengthen Native American identity and values, including balance and respect for other living things. Further, these values and practices support conservation by reducing negative human impacts on Bear Grass and increasing a Native steward's awareness of plant population changes. Some aspects of the reciprocal nature of the relationship of Native Americans to Bear Grass are detailed in Table 2.2.

i. Maintaining harmony and balance with the environment

Maintaining harmony with the natural environment requires observing plant and environmental cycles and changes. Sara Siestreem, artist, educator and member of the Confederated Tribes of the Coos, Lower Umpqua and Siuslaw Indians, described the importance of regular contact with the Bear Grass as a way to connect with and care for plants and to recognize seasonal cycles.

> *We visit the gathering sites throughout the year to communicate with the plants, pray, check in on how they are doing and see if we need to care for them in any way. By doing this throughout the year we can see how the seasons are changing and be ready when it is time to gather, since each year things change.* Sara Siestreem (Hanis Coos)

All weavers mentioned that when gathering you would take only what you need. For example, in the quote below, Frank K. Lake, Karuk descendant and Research Ecologist for the U.S. Forest Service, describes removing a small portion of leaves per plant from a small portion of plants in a given area. Most weavers also mentioned proper technique for gathering leaves, though the details of harvest varied by region. Following cultural protocols for harvesting reinforces balance between people and natural world.

> *There is tribal philosophy that you never gather more than you can use...you limit how much you harvest from any one plant or within one area. You've got to do skips and gaps and maybe even along a three mile ridge area that burned, maybe you hit ten different places along those three miles, you are not just concentrated on one place.* Frank K. Lake (Karuk descendant/USFS)

Two weavers on the Olympic Peninsula mentioned the practice of not removing the "heart" or most central whorl of the plant where the meristem is located. June Ward is a fifth generation Makah weaver and weaving teacher. She describes how she was taught about harvesting practices:

> *Grandma was very firm about teaching us first ... not to rip the heart out... how we have to pull the outer stems of the Bear Grass off without damaging the plant, and no overharvesting ... Grandma would show us, and we would get in trouble if we pulled the whole root out, or the heart.*
> June Ward (Makah)

ii. Spiritual aspects of gathering reinforce identity and values of respect and reciprocity
Five of seven weavers also described the spiritual conduct and plant-human relationship that is part of the way to gather and care for Bear Grass. This spiritual conduct reinforces identity and cultural values of respect and harmony. In the following quote, Frank, as well as weaving instructor Elaine Rice St. Martin who lives in the Portland, Oregon area, describe spiritual practices they have been taught in relation to gathering wild plants.

> *What I've always been taught is when you're gathering from the Earth you have that respect and understanding of what the Earth is giving back to us … for our lives. And going to gather and asking if we can gather and also taking an offering. It could be an offering of food, it could be an offering of money, an offering of tobacco. And going and asking. Sometimes a tree or plant are not ready to be harvested. You'll kinda know. They'll guide you and they'll tell you when to stop harvesting…I usually know when it's time for me to stop harvesting. I know. It's just like a spirit tells me: "okay, that's enough," and "do you need all that for what you want to work with?" So that's how I do it, and I pray, and I give thanks.* Elaine Rice St. Martin (Tuscarora/Seneca)

> *I was taught culturally… that there is a proper way to gather Bear Grass. …there is cultural protocol for introducing yourself to the area before you gather, offering a song or some kind of other offering, typically tobacco or wild celery root,* Lomatium*, some kind of way of acknowledging that plant's stature or status as a spirit being that you … have a stewardship responsibility with as human spirit to plant spirit. And so, the proper way to gather is a spiritual conduct.* Frank K. Lake (Karuk descendant/USFS)

Though only mentioned by one weaver, the long-term human-plant relationship of Native American communities to Bear Grass is evidenced in the existence of Bear Grass gardens. Sara shares about these gardens below:

> *Its presence in our historic baskets is also significant from an ancient gardening perspective. Typically, in this region Bear Grass is found in mountainous elevation. Our traditional homeland is at sea level. We have located extensive Bear Grass beds in close proximity to our traditional village sights. Also in and around these beds are as many as 45 other food, medicine, and cultural use plants. This phenomenon indicates a cultivation that would have taken many generations to establish.* Sara Siestreem (Hanis Coos)

iii. Maintaining harmony and balance within tribal communities

Gathering in the right way also included sharing with others and giving special consideration to elders who may have less mobility. Areas nearest to the road were left for elders, while younger and more able-bodied adults and teenagers would walk further to select an area to gather. Several weavers mentioned sharing Bear Grass leaves with family and community members who have a harder timing accessing Bear Grass including elders, and also mentioned Bear Grass as a gift with specific cultural meaning. Robert Kentta, Cultural Resources Director for the Confederated Tribes of the Siletz Indians, mentions gathering for others, while Sara discusses the meaning of Bear Grass as a gift.

> *There are a number of folks that gather it and some of them don't even use it, but they ... will grab a few crowns and lay them out in the sun and bleach them ... and then pass them off to someone who can use it.* Robert Kentta (Siletz)

> *I gather it to gift to my future students and as gifts to other Indigenous weavers. A gift of Bear Grass from our Ancestors is a high honor to share with another weaver. If it is one of my students, it is a way to connect them with their grandmothers and grandfathers. If it is to an outside tribal person it is a way to extend that honor to them in gratitude of our relationship and in the hope that the Coos, Lower Umpqua, and Siuslaw will be remembered and present in the baskets they make.* Sara Siestreem (Hanis Coos)

Below, June discusses the importance of sharing her baskets, while Elaine discusses sharing of weaving techniques.

> *I have a long list of people who want stuff and I do not take money from nobody and if I can do it and if I have time, I do it. I don't charge family...If I want to give something away, I just give it away. Just like in the old days...we have memorials, we have coming-of-ages, or naming parties or something, ... so we like to give out bundles of Bear Grass, bundles of bark, a lot of baskets, carvings and stuff.* June Ward (Makah)

> *I have some friends that I go and basket weave with and they have their own style and I've learned some of their techniques and how they would kind of share back and forth and that's really kind of nice. They see something I do and go "I wanna do that!" ... If they want to learn, I'll show them how I do it.* Elaine Rice St. Martin (Tuscarora/Seneca)

Part of leaf processing also includes doing this with other people, a practice that would connect people to Bear Grass traditions and increase social cohesion. Below, Frank describes the social and cultural values associated with processing leaves together.

> *The processing of it, you can do it by yourself, but I find there is a lot more social strength together. When people are around, you know, and you are like, hey, I got a big old thing of Bear Grass I just got and drying it out in park or something, out in the sunlight, and you get together and have a few friends help you sort it and like, hey, I would like to weave with bigger stuff and I would like to weave with smaller stuff and see people kinda divvy up what they have ... getting together and many hands, light work ... and for sure a little story and you have a little transfer of knowledge in the process of preparing your Bear Grass.* Frank K. Lake (Karuk descendant/USFS)

Part II: Changing abundance, quality and access to Bear Grass

It's getting hard to find. It's like gold. So far, I've been lucky. I have been able to get enough to keep me going through the year. June Ward (Makah)

i. Weaving techniques and desired leaf qualities

Bear Grass is used in a wide array of weaving techniques, not limited to baskets. Weaving techniques mentioned by weavers in this study included: half-twist overlay, full-twist overlay, false embroidery, wrap twining, imbrication on coiled baskets, braiding, wrapping, plaiting, and beading. Cultural art mentioned that utilized these techniques included various styles of baskets, dance aprons and dresses, headrolls (Bear Grass used as stuffing), jewelry, pouches, placemats and hats (including ceremonial caps) (Fig 2.1).

All weavers who discussed leaf quality wanted longer leaves, but preference for leaf width varied. One benefit of longer leaves is that the Bear Grass leaf does not have to be replaced as often as you are working on a basket or other weaving project. Weavers who gathered outer leaves wanted wider leaves. For these weavers, leaves for finer weaving were processed from larger leaves by “cleaning” (scraping the leaf with a knife to remove the midrib and to remove layers of leaf tissue to make the leaf tissue thinner and suppler) and then sometimes processed further by passing leaves through a handmade cutter that would provide a thin and consistent leaf width. Outer wider leaves were preferred by two weavers in southern Washington, while inner, thinner leaves were preferred by two weavers in northern California/southern Oregon. Leaf taper (the change in leaf width along the leaf axis) was an undesired leaf characteristic for some weaving techniques, while consistent taper was desired for other styles. Topography, shade and fire were related to desired leaf qualities. Partial shade, the presence of fire and not too steep of a slope were associated with better leaf qualities. Sun-scorched leaves, leaves that were too coarse or leaves with insect herbivory were undesired.

ii. Changes to plant abundance, leaf qualities and access

Leaf quality and plant abundance were generally reported to be declining. Fire was considered beneficial to Bear Grass by all weavers who mentioned fire and was also understood by some weavers to promote desired leaf qualities.

Some weavers reported that desired leaf qualities are now harder to find. Leaf quality issues included leaves that were too small, and leaves with bug damage. Bug damage is mentioned by Robert below:

> *... it has been about 23 years, anyway, going up to the same place where we do the huckleberry management, that’s been really the primarily place that I get Bear Grass, there is always lots of it there in varying qualities, ... there is the bug issue that seems to be increasing a little bit every year probably.* Robert Kentta (Siletz)

Most weavers reported that the abundance of Bear Grass has declined. Two weavers and teachers of weaving who have gathered for decades on Mount Adams, WA report the following:

> *We had this one favorite spot that was open, that you could see St. Helens throughout the year. ... Oh, it was a beautiful spot ...But then the trees started growing and growing and growing… Bear Grass started disappearing. So now we can’t even use it. They get crowded out.* Jo Ann Hart (Cherokee ancestry) and her spouse, George Hart, discussing together

June from the Olympic Peninsula and Robert in central Oregon concur with these difficulties:

> *It’s getting hard to find... We went to one area and we looked, and we didn’t see not one bundle of Bear Grass. We spent hours up in the hills looking and couldn’t find not one bush. So, it’s getting hard to find. It’s like gold. So far, I’ve been lucky. I have been able to get enough to keep me going through the year.* June Ward (Makah)

> *We have a hard time here this side of the coast range getting access to good grass. There used to be more spots up in the coast range where it grew fairly well, but it’s disappeared from a lot of those places... It’s so over-harvested. Not much left.... There’s not as much, that’s for sure. It’s harder to find good pieces for baskets. We walked forever.* Robert Kentta (Siletz)

A few weavers felt Bear Grass was abundant or that at least that abundance was increasing. Collaboration across agencies and tribes was mentioned as a reason for the increasing abundance and quality in some areas.

> *It is both abundant and accessible.* Sara Siestreem (Hanis Coos)

> *It's improving, and part of that abundance has to do with... wildfires ... and partnerships, like the Six Rivers National Forest or the Orleans Ranger District, Roots and Shoots project, burning Bear Grass. The Orleans Ranger District has a record here of doing Bear Grass management, all the way back to the 1980s, with the basket weavers. ...It's just increasing that ability, greater partnership, increased Tribal-Federal government consultation, communication, and coordination on projects.* Frank K. Lake (Karuk descendant/USFS)

iii. Reasons for changing leaf quality, abundance and access

Reasons for decline included commercial harvest, lack of fire and lack of recognition of sovereignty. Reasons for increasing abundance included greater collaboration in forest management between Tribes and U.S. Federal and State agencies.

Commercial harvest was a concern mentioned by four weavers for the decline in abundance or decline in quality. The impacts of this commercial harvest are described in the four quotes below:

> *Non-native people, there's a lot of Bear Grass that's harvested, and harvested not in a good way and that depletes some of the Bear Grass areas. I think a lot of native people are really protective of their areas so that it's not overused, and that material is always there.* Elaine Rice St. Martin (Tuscarora/Seneca)

The native people pull beargrass one blade at a time and do not pull the middle of the plant out. Pulling the middle young leaves and stalk out will kill the plant. Beargrass is very sharp and will cut your hand if you don't pull it correctly so commercial people cut it off and we have seen evidence of this. This practice is not good on the plants. The last time went to harvest beargrass we did not find any that was suitable for basketmaking, even at the places we had previously gathered it. We always only took a small amount, a pound or two at the most. We have seen 39 gallon garbage bags of beargrass (rotted) left in the bushes that commercial pickers forgot or left on purpose if they were illegally harvesting it maybe. The commercial pickers sell it to those who sell it to Japan for floral arrangements, I've been told. The Forest Service doesn't even charge that much to get a commercial harvest permit. Jo Ann Hart (Cherokee)

You've got .... people in the woods [commercial harvesters], overharvesting, and they're cutting. They are just cutting everything with a special knife they had made ... and, their [emphasis] is quantity...they pack out mass quantities, and they have really stripped a lot of the areas. A lot of people have secret stashes they don't tell people, and they keep hoping, and every year I go back to check that my plants' place is still intact and protected... They strip the area, which is not good and that's happening quite frequently. June Ward (Makah)

Somehow these folks find out about some of the best patches. Especially folks that are Bear Grass pirates. Going in without a permit. They go in and do a quick and dirty job. Use hoedads to bust up the clumps and only use the outer layers of the center clumps. They leave some of the best center stuff and they basically kill off the clumps too, to a large-degree this is by their harvest method. Robert Kentta (Siletz)

Lack of fire was also associated with a decline in the quantity and quality of Bear Grass due to competition, increased insect herbivory, lack of light and lack of nutrients. In this study, fire was considered to have a positive impact on Bear Grass or on the environment by all weavers except for one who did not comment on the effects of fire. The importance of fire culturally and ecologically is addressed in the two quotes below:

> *The way to care for it, more around the forest management, and for our cultural, our tribal preference down here is to have it burned. It can be a lower intensity fire, it could be a little bit moderate intensity fire, but you need the filtered light, or a canopy above at these sites so if you can get those biophysical or ecological conditions right.* Frank K. Lake (Karuk descendant/USFS)

> *In the old days, ... you ... would go in and burn the clear cut. And then a lot of people for some reason just did not grasp that concept. They thought we were burning all the little critters. This fire was so fast it only burned 2-3 cm of the top. And it kept the fuel down and we didn't hurt the critters. ... when we were burning them, the vegetation would come back just with ferocity.* George Hart

Changes to quality with lack of tribal management were also evidenced in changing leaf qualities in baskets. Below Robert describes a very old basket that still had uncut leaves protruding from the basket. These protruding leaves provide a glimpse of past leaf quality.

> *It was an untrimmed [very old] basket...You don't see that very often and it was surprising how long, thin [the leaves were] and it looked like it had to have been from a very managed stand of Bear Grass. Long, thin.* Robert Kentta (Siletz)

Care and management were also limited by lack of recognition of sovereignty. Without sovereign control over management practices as well as control over who can enter and use particular areas, it is difficult for traditional resource management to proceed in a way that favors production of Bear Grass plants of appropriate quality for weaving. Sovereignty was mentioned by three weavers. Below, Sara shares a vision of greater recognition of sovereignty, while Frank describes the implications of change in sovereignty for cultural burns.

> *My goal is that future generations do not need "permission" from these governmental agencies to follow their inherited lifeways (gathering, etc.). At this point in our cohabitation, we are working to educate these entities that we will be exercising our sovereign rights to gather and practice our traditional activities on the land and in public spaces.* Sara Siestreem (Hanis Coos)

> *In the big picture, it used to be more family, sovereign kind of fire burning, and at that level, and now it's more of tribes and basket weavers depend upon the agency or a cooperative burn between agencies and the tribe to do that.* Frank K. Lake (Karuk descendant/USFS)

Two weavers discussed the relationship of climate change to the quality of Bear Grass plants for weaving. Concerns included the effects of drought, increasing temperatures, and changes to the type and timing of precipitation on plant quality. These changes were understood in some cases to reduce Bear Grass vigor, shift Bear Grass phenology forward, reduce leaf quality, change the timing of traditional gathering, and, from a social perspective, change perceptions of what is considered a traditional gathering site. Climate was also discussed in the context of its impacts on fire severity, which in turn impact Bear Grass gathering areas.

Earlier snowmelt and late snow after snowmelt were understood to reduce leaf quality for weaving. For example, creating kinks in leaves that reduce quality, as described by Robert below:

> *Sometimes you can have like a little bit of early spring and it will start sprouting up and then you will have another late snowfall, and you can tell sometimes that that grass gets a little kink in it. The new growth has that weight on it.* Robert Kentta (Siletz)

Drought was described to directly impact Bear Grass plants, but also to contribute to a longer fire season. As Frank describes below, drought in Northern California, in combination with the legacy of fire suppression and exclusion, produces the conditions for high severity fires that can destroy Bear Grass gathering sites.

> *...The last couple of years, precipitation is changing ...whether that's the snow level elevation, how much snowpack there is and then when that melts off ... the fact that we are having later fall rains means that there is a longer amount of time, especially if the fog is changing, that you don't have that soil moisture and precipitation influence on the plants. So, I think that's affecting it. People are seeing that what used to be a lush, vigorous patch, now kind of declining. I think part of that was the drought, but then also with the increased temperatures and the lengthening of the fire season, you have conditions now where areas that might have been more frequently burned by families, pre-fire suppression, now have thicker forest, heavy fuel loads, much more dust litter and logs and branches, and when fires do burn at the most extreme conditions of the mid to late summer, then you have high severity and you are literally cooking the soil and killing the plants directly because of too much fuel on them.* Frank K. Lake (Karuk descendant/USFS)

The multi-generational connections to particular gathering sites can sometimes be lost when Bear Grass plants at that site are affected by high severity wildfire. Communities have the cope with the process of losing those connections to place and forming new connections in other areas. Frank discusses this below:

> *And I see those kind of changes in forest management, or the legacy of forest management, the effects of climate, and the increased intensity and severity of wildfire ... that is affecting, in one or two generations, the perception of what is a gathering site and it being traditional, versus now, like, oh, this area is impacted by wildfire, we have to find new places...I see the struggle most tribal communities face, like, I have always gone to this place and I have always gathered here off this road, but that place has basically been high severity affected. It's not going to recover in my generation, in 30, 50 years, and so where do we find other places? There is that part of that coping and that process, of like, where's the next suitable place that we could get it?* Frank K. Lake (Karuk descendant/USFS)

Part III: Resilience of Native American Bear Grass traditions through adaptive practices

Weavers described alternative ways to care for Bear Grass when they were not able to burn, or as a result of climate change or lack of recognition of sovereignty. Substitution of Bear Grass for other materials was also discussed, though was generally considered unacceptable as an adaptation.

i. Alternative management techniques

We have rights to use the space and gather the plants uninhibited (kind of). That means, we can gather there but we could not say, use burn management. Sara Siestreem (Hanis Coos)

Below weavers discuss adaptive practices in the absence of fire such as pruning, keeping areas hidden, and burning individual plants rather than entire areas (broadcast burning).

> *We do a lot of pruning activity and so far, that is getting us at least useable materials and maybe not the best quality, but we are able to get good volumes of it for teaching others and for our own uses. Getting by.* Robert Kentta (Siletz)

> *In our contemporary times our land management strategies are severely inhibited by outside (State, Federal, and Private) interests in many of our traditional sites. Our Bear Grass gardens are on State lands. Fortunately, they happen to be in a protected area, so they will not be subject to disturbance by construction, etc. and we have rights to use the space and gather the plants uninhibited (kind of). That means, we can gather there but we could not say, use burn management. The kind of management we do is to remove litter or trees or such that might have fallen on the beds and keep the beds hidden from view by blocking any trails to them that may have emerged in our absence.* Sara Siestreem (Hanis Coos)

> *...People do it covertly, or do patch arson burns, which I am aware of. With their Bick lighter or a propane burn, and you singe the Bear Grass, and then you just douse it out with a bucket of water... and then you still get a couple of plants burned, and so I know people even practice that, without setting a forest fire, they just burn individual tufts, to cause that batch to renew, just on the down low.* Frank K. Lake (Karuk descendant/USFS)

Given climate predictions for less consistent snowmelt at gathering sites, one Tribal resource manager described plans to geographically shift management efforts to a different place that is predicted to have more consistent snowpack.

> *I think [drought and temperature changes] will have a negative impact.... Where we do the main Bear Grass and huckleberry collecting, there is prediction that the huckleberry could be greatly diminished up there, just by the predictive modeling of effects of climate change. So, up where the big fires are burning now, ... that was one of the areas we were looking at to focus more of our efforts just because there might be more consistent snowpack, the prediction is for where we do a lot of our main collecting now that there could be less reliable snowpack....* Robert Kentta (Siletz)

ii. Substitution

I am glad that we haven't found an easily-accessible commercial material to replace our roots and sticks. That is part of the connection, to places, but also the ancestral tradition. Robert Kentta (Siletz)

While substitution of other weaving materials for Bear Grass could be considered an adaptation to changing ecological and social conditions, Bear Grass was generally considered irreplaceable. Substitution of Bear Grass by raffia (*Raphia* spp., purchased online or at craft stores), corn husk (*Zea mays*), reed canary grass (*Phalaris arundinacea*), sinew and slough sedge (*Carex obnupta*) were mentioned, mostly because these materials were easier to acquire and easier to process for use in weaving. Substitution was seen in a negative light by all but one weaver, as either impossible or as representing too much loss to the basketry tradition and/or to the connection with the natural world. Substituting Bear Grass for other materials led to a loss of techniques (other materials cannot provide the same stitch appearance or weaving product), a loss of family traditions (substituting meant there was less distinction between family weaving traditions as baskets with substituted materials looked similar), loss of connection to the natural world through the tending and gathering process, and disruption of ceremony and rites of passage that require Bear Grass. Some of these reasons for substitution are shared by Jo Ann in the following quote:

> *A lot of people don't like using Bear Grass in Basketry because it's too much work. Reed canary grass is sometimes used as the substitute for Bear Grass because its more accessible; its invasive actually here in western Washington and you don't have as much preparation work to do for use it in basket making...Weavers are all switching to other materials. They're using artificial sinew for wrap twining now which works but doesn't even look the same because they don't get that slant in the stitches so I think it looks terrible. The stitch is more straight up. There are only two weavers that I know of from the Makah Nation that still use traditional Bear Grass in their baskets in the old way.* Jo Ann Hart (Cherokee)

In response to the question: What is lost when people are no longer using Bear Grass and are substituting other materials? June said:

> *The history and the carrying on of the family traditions, and of patterns and styles...when they start doing all these similar raffia and sinew baskets, you don't know who they belong to because there is not history of color, of style, it's all gone... so it's hard to differentiate, who it belongs to. That is a really serious concern of losing style and techniques... the families of the Bear Grass weavers... they'd make a different whale or a different bird, or bright vibrant colors, or some families would just stay with certain colors.*
> June Ward (Makah)

The ceremonial significance and irreplaceability of Bear Grass is exemplified in the following quotes:

> *For us, we haven't done a lot of switching ... Especially when you get to something like basket caps that are for ceremonial use...for our style of southern Oregon/Northern California, it pretty much takes those traditional materials to make a decent cap. There is something about that not wanting to break with those traditions, especially for those ceremonial use pieces. ... I am glad that we haven't found an easily-accessible commercial material to replace our roots and sticks. That is part of the connection, to places, but also the ancestral tradition. It's kinda something special, I guess, to work with sticks and roots.* Robert Kentta (Siletz)

> *Bear Grass is a significant weaving material to the Coos, Lower Umpqua, and Siuslaw people. When it is present on a basket it indicates the basket is used for ceremonial purposes.* Sara Siestreem (Hanis Coos)

Part IV: Recommendations for strengthening biocultural connections

What are my recommendations for strengthening cultural traditions related to Bear Grass? Is to have kids put down their phones, get outside, be engaged in things by respecting your elders and doing things with your elders. Frank K. Lake (Karuk descendant/USFS)

Before asking for recommendations, I asked weavers how common Bear Grass weaving was in their community and how this had changed over time. Interest in Bear Grass weaving traditions was described as growing or reawakening in some Native American communities, as demonstrated in the first quote below, while other weavers described its endangered status in their community (second quote directly below). All weavers wanted to support or strengthen Bear Grass weaving practices.

... It is a total joy to witness the natural way they [children] are growing up in their culture, it's Legos +Spruce Roots+ Barbie's +Bear Grass +monster trucks+ absent minded humming of traditional songs. At our last workshop I brought a large (10 gallon) tule storage basket filled with a few years of scraps from all the materials we use. I dumped it out on the floor and had the youth sort through it. They knew every plant in the mix, sort of grumbled about it too, like "that's cat tail, duh!" totally unaware of how much they knew or how special and bitter-sweet it is to be the first generation in 170 years to grow up this way. Sara Siestreem (Hanis Coos)

It's a dying art. Nobody wants to take the time to clean it, or it's too hard and they give up too soon, and with the young kids now, they don't have the elder teachings from their elders because most of the families' elders are gone, so they are not imprinted with history and stories and techniques or anything. June Ward (Makah)

Weavers gave diverse recommendations for revitalization of Bear Grass weaving traditions within the spheres of education, political action, technology and economic access (Fig 2.6). These ranged from paid internships for youth to learn weaving, starting youth on simple projects that build their confidence, greater collaboration between Tribal and Federal and State governments and greater recognition of tribal sovereignty. Recommendations generally fell into two broad categories of 1.) increasing access to Bear Grass and 2.) increasing connection to Bear Grass traditions within Native American communities.

i. Improving access

One recommendation for strengthening traditions was to improve access to quality leaves through restrictions on commercial use, as described in the two quotes below:

Wouldn't it be nice if the floral industry said, "We're not going to use Bear Grass?" [laughs] Just to get away from the problems of illegal harvest and bad collection methods and depletion of patches and all of that... Some of the areas do shut down their permits, and then some of those collectors then focus on other areas. So, it's not like it limits the impact, it just shifts the direction of it and maybe focuses it even more in other places. Robert Kentta (Siletz)

Particularly if some of those areas are sensitive or are of high value to tribes, to not only promote their use and access, but perhaps, to find other ways to, under Chapter 32A, Culture and Heritage Cooperative Authority Act on seasonal closures, maybe even preventing the floral industry competition or understanding the difference between what the floral industry wants for their arrangements versus what different weaving cultures need for their uses of Bear Grass and basically finding ways to minimize competition and provide opportunity and access and high quality material to maintain that Bear Grass-related weaving cultural knowledge and practice. Frank K. Lake (Karuk descendant/USFS)

Collaboration with Federal government entities was also described as a means to increase access to quality Bear Grass patches and leaves. Below, Frank shares the evolution towards collaboration in his community:

> *Then, with the creation of the Forest Reserves, the National Forests, fire suppression policy and fire exclusion, they weren't able to burn so much. So, that really changed the role of fire use and stewardship. … but now with greater cooperation and coordination and consultation of Tribes, between the Forest Service and Tribes in consultation with the basket weavers and organizations, there's increased interest in integrating that tribal knowledge and ethnobotany or basketry use for Bear Grass into the landscape restoration strategies. Informing the crews who are out there doing the fire suppression or the fuels work about how to manage and try to promote Bear Grass, and not to hurt it.... now more the Forest Service burns are a little bit accessible, the burns are specific for the Bear Grass, not in response to wildfires.* Frank K. Lake (Karuk descendant/USFS)

Recognizing tribal sovereignty through reparations and reserving natural areas for exclusive tribal use was also recommended as a way to increase access. This approach would also contribute to the healing of tribal communities and non-tribal communities through recognition of past and continuing injustices. Sara shares a vision of justice and healing below:

> *... my vision is that significant spaces be returned to the tribes and removed from "public" activity. There are so many of our sacred sites that are currently used for public recreation or industry. It is a spiritual affront to share these spaces and to witness the devastation that many of them endure for the profit of non-tribal interest. The only way these spaces can heal is if they are returned to their ancient stewards and the prevailing governmental entities financially support the repair of the land. This would include removal of refuse and contamination left behind as well as retraining their people and the public that these spaces are no longer public and or economic opportunity for non-tribal entities.* Sara Siestreem (Hanis Coos)

The ability to learn one's own basketry traditions was also described by one weaver as limited by lack of time due to other work responsibilities. Paid internships for youth were therefore recommended as a way to increase access to weaving traditions.

> *It would be interesting to try and see if a program set up where these interns or apprentices got a stipend, some sort of an hourly rate for developing their skills so that they could afford to dedicate their time to that purpose instead of flipping burgers at McDonalds or something, just trying to get by that way.* Robert Kentta (Siletz)

ii. Strengthening connection to the environment and to each other

In addition to increasing access, weavers provided recommendations for revitalization of Bear Grass traditions through strengthening connections of Native Peoples to the land and to each other.

Engagement with the outdoors and with elders by reducing use of cellphones and computers was recommended by four weavers. Supporting basket weavers financially, socially or through natural resource management was also recommended by most weavers. Both quotes below describe the need to connect youth with nature. The first quote also provides additional recommendations that span social, economic and ecological dimensions.

> *What are my recommendations for strengthening cultural traditions related to Bear Grass? Is to have kids put down their phones, get outside, be engaged in things by respecting your elders and doing things with your elders. And then, really, for the basket weavers, or the cultural practitioners who are teaching it, finding ways to support what they need. In both resources from everything from a good working truck, having gas money, to having a core of people that they can mentor that can go along with them to have that cultural enrichment. And then also on the land management side, providing suitable areas in the landscape that are accessible, that have the right kind of forest conditions, that if there is fire use or a fire management strategy, that that incorporates the cultural interests and values for promoting Bear Grass and its conditions and then making sure that that is communicated between all those entities involved in landscape restoration or management.* Frank K. Lake (Karuk descendant/USFS)

> *One of the biggest problems in society is phones, texts...the younger generation, they don't want to be bothered with that stuff [gathering, weaving]. They're don't want to be dirty. They want to sit and watch TV. Or sit and play on the phone or on the computer with video games and stuff...Using technology is preventing kids....It happened so fast, in my humble opinion, between computers and microchips and all this other stuff. The human brain has not been able to catch up.* Jo Ann Hart (Cherokee) and her spouse, George Hart, discussing together

Education was mentioned by most weavers as a recommendation to strengthen cultural traditions associated with Bear Grass. This almost always referred to Native American teachers teaching other Native Peoples (primarily youth). Recommendations including teaching youth who show interest in weaving, starting with a simple project, keeping traditions within tribal communities, hiring Native American teachers to teach Native American youth, continuing to hold Native American basket weaving conferences and specifically teaching some of the most challenges aspects of leaf preparation for weaving separately. Also mentioned was educating the public about tribal sovereignty and about the importance of Bear Grass to Native American people. Some skills and values necessary to carry on Bear Grass traditions that should be taught to people learning the traditions and which were mentioned by at least two weavers are listed in Table 2.3. In the quote below, Elaine shares about the importance of starting simple and building confidence in new weavers.

> *I think if they're interested, sit down and work with them...and teach something simple. ...working with cattails and making flat mats that could be done within 20-30 minutes. Get them started and finish some kind of project they can take home with them. Some got really excited. They really want to know. And some just kind of like, they're not sure yet. but they're really fascinated with what they can do. They think they can't do something and then they do it and go "wow!".* Elaine Rice St. Martin (Tuscarora/Seneca)

Several weavers mentioned that Bear Grass traditions were declining over time because of the difficulty and skill involved in preparing the material. The recommendation was therefore to teach this challenging skill of "cleaning" the Bear Grass in separate classes. This refers to scraping the leaf with a knife to remove the midrib and continuing to scrape the leaf until it is very thin and supple.

> *I think it's a good idea to have some classes to learn just how to clean it. People wouldn't get so frustrated and discouraged if they could get the technique down enough.* June Ward (Makah)

Table 2.1. Overarching findings from the ethnographic study

Key findings
• The care and gathering of Bear Grass reinforce identity and help maintain harmony and balance with the environment and within tribal communities. • Tribal communities face challenges accessing quality Bear Grass leaves for weaving based on changes to management, commercial harvest, lack of recognition of sovereignty and climate change. • Tribal communities have adapted to these challenges through alternative management techniques, spatio-temporal shifts in management and gathering, and possibly through more labor-intensive leaf processing. • Recommendations to support revitalization of Bear Grass traditions within native communities mostly fell within the categories of increasing access to quality leaves and increasing connection of native people to these traditions.

Table 2.2. Reciprocity as demonstrated through Bear Grass traditions

How native people care of Bear Grass	What Bear Grass provides to native people
• Prayer • Offerings (song, sacred plants) • Periodically checking in on plant populations • Pruning surrounding vegetation • Burning plants or populations • Mindful, low impact leaf harvesting • Protection from activities destructive to plant populations • Appreciation	• Connection to ancestors and ancestral traditions • The ability to perpetuate traditional ceremonies • Cultural and familial identity through weaving technologies specific to tribes and to families • Connection to the world of nature through tending and gathering • Flowering as an indicator that the huckleberries are ripe • Gifts (of leaves to baskets) as a way to show care and love for other family and community members • Social cohesion through processing together and sharing • Artistic expression • Confidence gained through learning and mastering weaving techniques • Beauty appreciated in baskets or regalia • Feeling of security and greater health for babies held in baby baskets • A way to hold and carry important objects • Livelihood option

Table 2.3. Summary of the responses of weavers regarding what should be taught to someone learning Bear Grass weaving traditions

Teaching	**Description**
Locating the plant	What it looks like, where to find it, and the biophysical conditions where it has the best quality
Respect and reciprocity	Spiritual conduct; Not overharvesting
Processing the leaves	Learning to “clean” the leaves by scraping with a blade; Processing with others
Sharing the leaves	Giving to others in need
Keeping traditions within Native American communities	Some techniques should only be taught to people with a cultural connection to the technique; Only native people should be weaving with Bear Grass
How to handle Bear Grass	Wear gloves to gather if needed; Don’t run your hand the wrong way along the blade to avoid being cut; Use the right side of the blade when weaving






Figure 2.1. Beargrass weaving artwork and harvested bundles by Sara Siestreem (Hanis Coos). Top left: Pray for rain dance cap, Top right: sequoia, Middle left: Mexeye Kwexw Axu, Middle right: Dasots' tobacco pouch, Bottom left: harvested bundles, Bottom right: harvested and sorted bundle. Photos and artwork by Sara Siestreem (Hanis Coos).

Figure 2.2. Additional beargrass weaving traditions in the Pacific Northwest. Top left: Beargrass hanging for future use after sun bleaching. Top center: Placemat of variously dyed beargrass in wrap-twined style. Top right: Jo Ann and George Hart holding some of their favorite baskets they have made. Middle left: Wrap twining on a trinket basket, purse and doll. Upper middle right: Wrap twining and plating of beargrass on a large purse by Jo Ann Hart, Bottom left: Robert Kentta (Siletz), holding a dance apron he made with beargrass wrappping above gray pine nuts (photo credit Gilbert Fredeluces).

Bottom right: Dance apron by Robert Kentta (Siletz) incorporating beargrass braids and beargrass wrapping (photo credit Robert Kentta). Other photos by Georgia Hart-Fredeluces.

Figure 2.3. Beargrass on Mount Hood National Forest, Oregon, 2015-2017. Top left: beargrass plant one year after a wildfire burned its lower leaves, Top center: Towhee eggs under a beargrass plant, Middle right: beargrass clump in bloom, Bottom: Mass flowering of beargrass in 2017 after a 2014 wildfire. Photo credits: Georgia Hart-Fredeluces.

Figure 2.4. Commercial harvest of beargrass. Left: Legal commercial harvest of beargrass by three men holding a permit and standing next to their harvest near the High Rocks area of Mount Hood National Forest. Photo credit: Amber Sprinkle, USFS. Right: Beargrass leaves sold at a supermarket as part of a holiday greens mix in December in Honolulu. Photo credit: Georgia Hart-Fredeluces.

Figure 2.5. First author (smaller basket) and her spouse's (larger basket) first attempt at red cedar bark (Thuja plicata) baskets incorporating a small amount of beargrass (white band) taught by Elaine Rice St. Martin (Tuscarora/Seneca). Photo credit: Georgia Hart-Fredeluces.

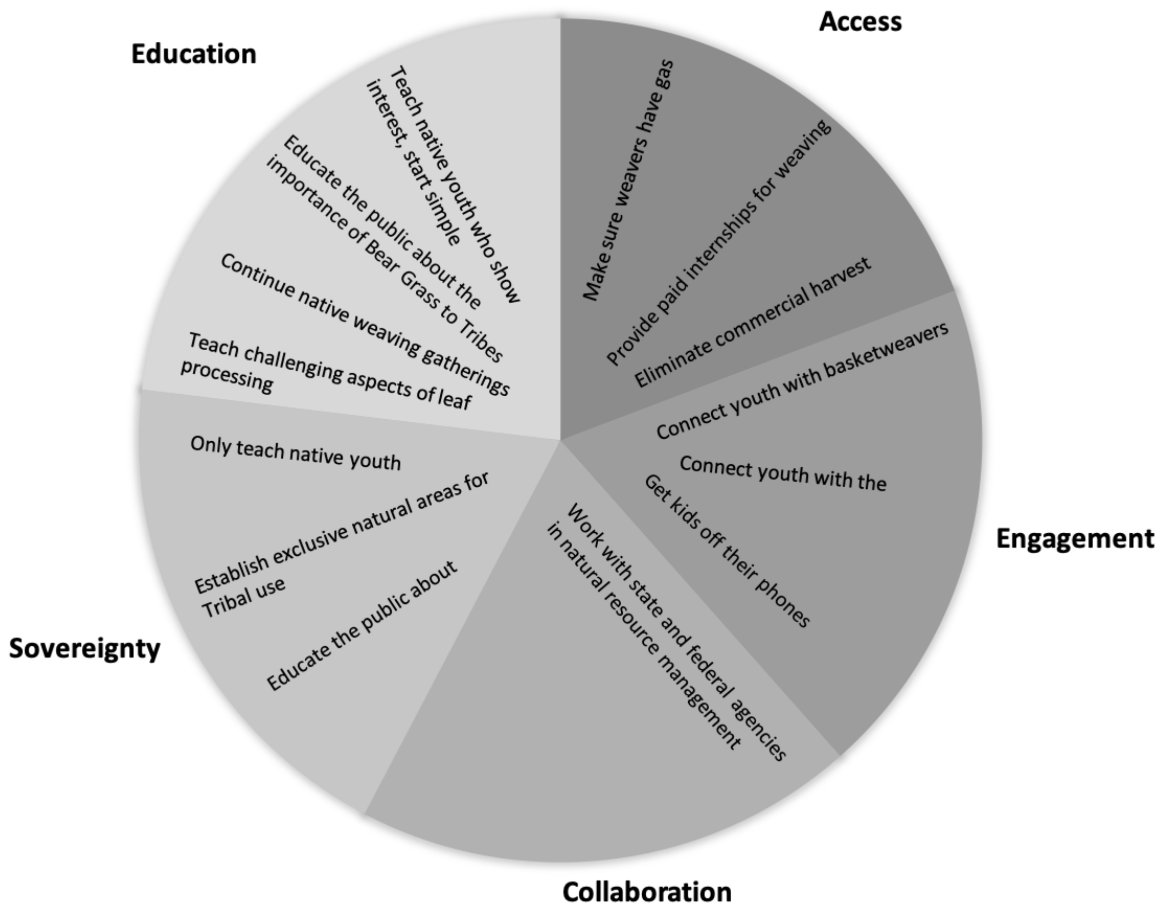


Figure 2.6. Recommendations of weavers for the restoration of Bear Grass traditions

Discussion

The perspectives and recommendations shared by weavers and cultural practitioners in this study provide insights into the adaptive practices that increase resilience in social-ecological systems. Weaver recommendations also provide practical steps, from ecological, cultural, political and economic perspectives, that can be taken to strengthen biocultural practices. There are, however, challenges associated with interpreting the findings of a study based on a small sample size. While individuals in this study are considered experts or leaders in their communities, they cannot speak for entire communities, tribes or regions. Throughout the paper, I was careful to note the number of weavers who shared a given recommendation or concern. Further, by placing the findings in the context of the literature, I am able to explore the level of support for the themes I share. As other authors have mentioned before me, sample size in collaborative and research projects with Native Peoples is sometimes limited by past and continuing injustices faced by Native American communities. Broader recognition of the impacts of colonialism, of tribal sovereignty and treaty and other rights within the larger non-native community would facilitate collaboration and knowledge sharing in projects like this in the future. This type of education of the broader public was also specifically recommended by weavers in this study as a way to support Native American cultural traditions.

Care of culturally significant places helps to reinforce identity and reciprocity with the environment and with each other

The idea that care of culturally significant species and places is integral to indigenous epistemologies and that it strengthens identity and helps to maintains harmony and balance with the environment and with each other (i.e., reciprocity) has been shared by several authors (Garibaldi & Turner 2004; McGregor 2007; Berkes 2012; Baldy 2013; Kimmerer 2013; Turner & Spalding 2013; Vaughan & Vitousek 2013; Vaughan 2018). Many cultural protocols shared here overlap with those reported elsewhere as part of indigenous worldviews and philosophies, including taking only what you need (Akutagawa, Williams & Kamakaʻala 2017; Vaughan 2018), sharing an offering of some kind before gathering (LeCompte-Mastenbrook 2015), sharing what you gather with others (Baldy 2013; Vaughan & Vitousek 2013; LeCompte-Mastenbrook 2015; Akutagawa *et al.* 2017), special consideration for elders (LeCompte-Mastenbrook 2015; Akutagawa *et al.* 2017; Vaughan 2018), and rules about who is taught traditional practices, including keeping traditions within indigenous communities (Keawe, Macdowel & Dewhurst 2014). Some of these practices have also been described specifically in connection to Bear Grass, such as taking only what you need (Baldy 2013), and the sacredness of the plant (Shebitz 2005), reciprocal and ethical relationship with wild-gathered plants including Bear Grass, and consideration for elders (Baldy 2013).

Preferred leaf characteristics and their relationship to cultural perpetuation

Preferred leaf qualities from this study were in agreement with that reported in other studies. The preference for leaves in semi-shade was mentioned by three weavers in this study, and is also documented by at least three other studies, which mention that leaves in the shade or semi-shade are less brittle (O'Neale 1932; Nordquist & Nordquist 1983; Hummel & Lake 2015). The practice of avoiding the "heart" (inner leaf whorls) of the plant when gathering was mentioned by two weavers in Washington State in this study and concurs with a study of Bear Grass gathering by a Nisqually family, but this family gathered inner mature leaves (Hooper 2015). Outer leaves were preferred by two weavers on the Olympic Peninsula of Washington, while inner leaves were preferred by two weavers in southern Oregon/Northern California. These regional differences in leaf preferences are similar to that reported by Hummel and Lake (2015), where Northwestern California weavers who primarily wove twined baskets and needed inner thin leaves, while Columbia Plateau weavers who primarily wove coiled baskets needed outer wider leaves.

However, one weaver on the Olympic Peninsula, who identified as a fifth-generation weaver, used the larger, wider Bear Grass leaves primarily for twining. She would scrape and split wider, coarser leaves to the appropriate width and pliability for twining. This sort of intensive processing of large wide leaves for use in fine basketry could be an adaptation to the declining availability of long thin leaves. Given that this weaver also described the skill and labor involved in this intensive leaf processing as a major obstacle to the continuation of Bear Grass basketry traditions in her community, one obstacle to revitalizing traditions may be creating another obstacle in a negative feedback loop (Liu *et al.* 2007). Specifically, not being able to access leaves of the appropriate quality means that you have to work harder to process the leaves you gather into a quality sufficient for weaving, making it more likely weavers will substitute other materials for Bear Grass and perhaps less likely that new weavers will learn this cultural art.

While a larger number of weavers would need to be interviewed to get a clearer picture of the contemporary diversity of leaf quality preferences, there are clearly differences by weaving style, as well as variation at regional, tribal, familial and individual scales (Hummel & Lake 2015). Resource managers may want to work with a number of weavers in an area they steward in order to capture this variation and then use that information to facilitate access to quality leaves.

Challenges accessing quality Bear Grass leaves for weaving

Indigenous Peoples' lack of access to culturally significant plants is widely reported problem (Anderson 1996; Shebitz 2005; Dobkins *et al.* 2016; Novak *et al.* 2018). Access to wild-gathered plants is governed by physical, economic, political, cultural and social factors (Lynch & McLain 2003; Dobkins *et al.* 2016). For Bear Grass, commercial harvest has been reported as a key factor limiting access (Lynch & McLain 2003; Shebitz 2005; Hummel *et al.* 2012; Dobkins *et al.* 2016). The fact that the majority of weavers in this study described commercial harvest as a cause of Bear Grass decline, without being prompted to specifically discuss commercial harvest, suggests limiting or restricting commercial harvest should be explored further as a mean to revitalize biocultural diversity. In chapter four, I demonstrate that harvest for cultural use (low intensity) has little or slightly positive effects on Bear Grass population growth. The different impacts of commercial compared to cultural harvest are therefore likely explained by harvest intensity (the amount of biomass removed per plant and the number of plants harvested within a population). Harvest intensity is known to have strong impacts on plant demography, with high intensity harvest potentially reducing plant survival, growth and reproduction (Mendoza *et al.* 1987; Lopez-Toledo *et al.* 2012). Cultural values and the spiritual connection of Native American cultural practitioners to Bear Grass reinforce low intensity harvest practices, which this dissertation suggests are helpful to beargrass populations.

Lack of fire was also commonly mentioned as a key factor restricting access to Bear Grass. Fire is used to increase access to culturally significant plants in many parts of the world (Kimmerer & Lake 2001; Anderson 2005; Fule *et al.* 2011; Perry *et al.* 2018).

Lack of fire limits access to other culturally significant plants including basketry plants such as hazel (*Corylus cornuta*), sweetgrass (*Anthoxanthum nitens*), and deergrass (*Muhlenbergia rigens*) (Anderson 1999, 2005; Kimmerer & Lake 2001; Shebitz 2005). The criminalization of Native American fire stewardship in northern California has long been an issue for access to Bear Grass (O'Neale 1932). This fire restriction also has multiple ecological consequences. For example, incidences of insect and fungal damage reduce the quality of Bear Grass and other basketry materials (Costanza *et al.* 2017). Traditional fire management is used to reduce insect damage to plants (Anderson & Morrato 1996; Voggesser *et al.* 2013), demonstrating multiple pathways by which fire suppression and exclusion limit access to Bear Grass plants of appropriate quality for weaving.

Adaptive practices

Adaptability, or the capacity of actors to adjust and innovate, has been identified as a key component of resilience in social-ecological literature (Walker *et al.* 2004; Folke 2006; Folke *et al.* 2010). Basketry is a cornerstone of Native American culture (Anderson 2005) and have been maintained through the cataclysmic trauma of European colonization (Berg 2007; Hatfield 2009). Inherently, surviving and maintaining cultural traditions has involved strong adaptive capacity on the part of Native American communities. Key adaptive practices documented here that help maintain Bear Grass traditions include: burning individual plants when you cannot broadcast burn, pruning and weeding instead of burning, keeping areas hidden and protected from commercial harvesters and other threats, and spatio-temporal shifts in care and management in response to climate change.

Burning individual Bear Grass plants as an adaptation to lack of fire was reported here as well as in two other studies in Northern California (O'Neale 1932; Lake 2007). The fact that practitioners are willing to risk the consequences of "arson" burns highlights the high cultural value of Bear Grass and the importance of appropriate leaf quality. Pruning surrounding vegetation was also reported in this study as an adaptation to lack of fire. Experimental evidence supports the role of vegetation removal in mimicking the effects of fire: an experiment on the Olympic Peninsula showed that mechanical removal and clearing of understory vegetation increased Bear Grass shoot production (Shebitz & James 2010). Pruning shrubs directly to produce high quality basketry materials is an ancient practice, though coppicing (a more severe form of pruning) has been reported, in one case, as a more recent management technique in response to lack of fire (Anderson 1999). Innovation, ingenuity and flexibility in management approaches, though not approaching the same effectiveness as burning, allow biocultural traditions to persist through change.

Protecting gathering areas from threats such as commercial harvest, logging operations, or even the presence of the general public is an adaptation to maintain Bear Grass traditions in the current political and social context. On federal, state and tribal lands, protecting Bear Grass can be challenging. Multiple incidences of poaching of Bear Grass from tribal lands for commercial use were reported to me during this study and can also be found in the literature (e.g., Vance *et al.* 2004).

Climate change was discussed by two weavers. Impacts included declining plant vigor with drought, declining leaf quality with more variable precipitation, and changes in the spatio-temporal gathering and tending practices. The timing of harvest depends on environmental and cultural factors. It was described in past publications to occur in June, July and August among the Karuk and Yurok of Northern California (O'Neale 1932), and in July for some Twana basket weavers (Nordquist & Nordquist 1983). In this study, one cultural practitioner reported that timing for harvest of Bear Grass was shifting earlier due to changing climate. Climate change was also described in its relationship to fire. High severity fires are now more common in some areas because of increased drought, longer fire seasons and the legacy of fire suppression (Hantson *et al.* 2015; Steel, Safford & Viers 2015). High severity fire can damage Bear Grass plants to the point that patches might take decades to recover. Since people and families have specific gathering areas they return to over time, this sort of fire damage creates a cultural/social shock and requires people to mentally adjust and find new viable patches for gathering. Adaptive capacity is again necessary to maintain biocultural traditions, or social-ecological resilience through disruption.

Substitution and irreplaceability

I, along with researchers before me, document substitutions of other materials for Bear Grass. The reason for substituting given by weavers in this study were that alternative materials are easier to access or less intensive to process. For example, Mary Schlick's work on Plateau weavers describes substituting raffia and other materials for Bear Grass (Schlick 1994). O'Neale describes Bear Grass as an easier substitution for the more elegant porcupine quills in dress caps (O'Neale 1932). While substitution is not uncommon, for most weavers in this study, and particularly those who were lineal descendants of Pacific Northwest Tribes, Bear Grass was considered irreplaceable. These weavers for whom Bear Grass was irreplaceable were also more likely to describe Bear Grass' ceremonial and sacred significance. This suggests that substitution of other materials would be insufficient to maintain biocultural traditions associated with Bear Grass.

Opportunities for revitalization of cultural traditions

Recommendations of weavers included ways to increase access to quality plants and to increase the connection of community members to weavers and to the land. These recommendations span the social, political, ecological and economic spheres and suggest multiple ways that natural and cultural resource managers could support Bear Grass cultural traditions.

Reserving areas for exclusive tribal use was suggested by weavers in this paper and has been implemented in some areas (Long & Lake 2018). One example is the Memorandum of Understanding between the Mount Hood National Forest and the Confederated Tribes of the Warm Springs Reservation to support huckleberry accessibility and enhancement (Wang et al. 2002, Catton 2016). Cooperative and collaborative management or co-management arrangements also have been implemented, including some that involve Bear Grass (Anderson 1996), though these arrangements can be made more difficult because of mistrust and historic injustices faced by Native Americans (Long & Lake 2018).

Educating the public about tribal rights and sovereignty in the Pacific Northwest is a topic that has been explored and suggested by other authors (Dobkins *et al.* 2016, p11). Washington State is among a handful of states that have implemented a public school curriculum focused on Native American sovereignty (Shear, Sabzalian & Buchanan 2018)(curriculum: http://www.k12.wa.us/ IndianEd/TribalSovereignty/Elementary.aspx), and these efforts could be expanded to other states.

Limiting or eliminating commercial harvest was suggested by several weavers but may be difficult to implement given the challenges of enforcement and the market demand for floral greens. Excluding commercial harvest of Bear Grass in exclusive areas may take some creativity, perhaps a locked gate without road access (Dobkins *et al.* 2016). Other authors have suggested changing labor policies to enhance Bear Grass harvest sustainability as these policies would influence who harvests, how long people keep a job as a harvester, and perhaps the way people harvest (Lynch & McLain 2003).

Holistic view of socio-ecological dynamics

While the results here focus on Bear Grass, weavers typically broadened their responses to include other species and components of the environment in their descriptions of care and management (Hummel & Lake 2015). Vegetation community level studies may be more informative than single-species approaches in understanding traditional resource management systems.

Conclusion

The resilience of Bear Grass social-ecological systems through cataclysmic change may be attributed to the high investment of actors in maintaining resources and connection to ancestral landscapes, as well as the strong capacity to adapt and innovate. The spiritual aspects of Bear Grass biocultural practices, and their expression in cultural values also likely underpin this resilience. Spiritual approaches to natural resource management help ensure resilience by providing a check on human behavior and reinforcing values of respect and humility. Cultural values also influence ecosystem management goals. Indigenous valuation of Bear Grass plants does not match Bear Grass conservation valuation and therefore increasing the visibility of indigenous practices and values would likely support biocultural restoration. For example, access and leaf quality are key cultural needs, while abundance and ecosystem services may be more important from an ecological perspective. Upholding tribal sovereignty and increasing tribal land ownership and tribal control over resource management as well as co-management are all paths forward that can potentially increase biodiversity, ecosystem services, sustainability and resiliency of cultural traditions. Creative collaboration across cultural differences and across the trust barrier are key and worthy challenges to achieve these goals.

CHAPTER 3. WILDFIRE, LEAF HARVEST AND ABIOTIC FACTORS DRIVE BEARGRASS DEMOGRAPHY

Abstract

Understanding how multiple simultaneous drivers interact to influence plant demography is an important step in predicting how plants will respond to global change. Across many parts of the world, changes in fire severity and frequency have altered forest ecosystems, but the interactive effects of major co-occurring drivers, such as fire and climate, and in particular the impacts on understory plants, are poorly understood. Further, for the thousands of plants species that are harvested as non-timber forest products, the impacts of harvest may also interact with fire, but this has rarely been investigated. To address these gaps, I collected demographic data on a fire-adapted understory plant, *Xerophyllum tenax,* in combination with individual-level soil moisture and light measurements over three consecutive years in high severity, low severity and unburned areas. I also conducted a leaf-harvest experiment in year two. I built mixed-effects models to understand the relationship of fire severity, and its potential interactions with leaf harvest and soil moisture, to *X. tenax* growth, survival and reproduction. Fire increased growth, sexual and vegetative reproduction, reducing survival only in the first year after fire. Leaf harvest that simulated gathering for cultural use reduced individual survival while increasing vegetative reproduction. Fire interacted with soil moisture and flowering, but not harvest, to influence *X. tenax* vital rates. Individual growth increased with early soil moisture in low-severity and unburned, but not high-severity areas. In sum, *Xerophyllum tenax* demography is affected by the interaction of abiotic and management factors. While I did not find interactions between fire and leaf harvest, I did find that the presence of fire changed the relationship of soil moisture to individual growth. Understanding current impacts and projecting future effects of management and changes to abiotic factors on understory species such as beargrass requires attention to interactions among environmental factors.

Introduction

Understanding how abiotic and management factors influence plant population dynamics is critical for predicting how plant populations will respond to global change. Although multiple abiotic and management factors often impact plants simultaneously, and may interact in their effects on vital rates, few demographic studies have examined these complexities (Ehrlén *et al.* 2016; Giljohann *et al.* 2017). Further, despite the ecological significance of the understory (Gilliam 2007), modeling of temperate forest dynamics rarely incorporates this stratum (Landuyt *et al.* 2018). Disentangling the effects of multiple drivers on understory plants can help provide management recommendations for the maintenance of ecosystem services including resources for wildlife. Fire stewardship and non-timber forest product harvest are examples of management that influence vegetation globally and may interact with the abiotic environment in their effects (Ticktin 2004; Gaoue & Ticktin 2010; Trauernicht *et al.* 2015). In the context of global change, understanding the nature of these interactions will be increasingly important for protection of biological and cultural diversity (Didham *et al.* 2007; Brook *et al.* 2008; Foster *et al.* 2016).

Fire is a key driver of plant population dynamics in many forest ecosystems (Agee 1993). Fire is also considered to be the most important management tool employed by humans; fire technology has been used in routine and controlled ways by hominids since at least the Middle Pleistocene (Bowman *et al.* 2011). In recent centuries, cessation of Native American burning practices in the western United States, reinforced through Euro-American colonization displacing tribes, has altered forested ecosystems (Christy & Alverson 2011; Trosper *et al.* 2012b; Christy *et al.* 2014). State and federal policies of fire suppression and exclusion, as well as climate change, have further influenced vegetation and cycles of disturbance (Dale *et al.* 2001; Walsh *et al.* 2015, 2018). This past fire suppression and exclusion can impact current fire severity and size, particularly in drier ecosystems with shorter fire return intervals (Hantson *et al.* 2015; Steel *et al.* 2015). In the Pacific Northwest of the United States, some forest vegetation zones are experiencing larger fire extent and greater proportions of high severity forest fire than in the recent past (Reilly *et al.* 2017). For fire-adapted plants, these changes could have dramatic impacts on population viability, but these effects have rarely been evaluated (Canales *et al.* 1994; Quintana-Ascencio, Menges & Weekley 2003; Souza, Schmidt & Conceição 2018).

Fire-adapted plants that are culturally significant may also undergo harvest pressure (Anderson 2005). Many are specifically managed through fire and harvest to obtain desired abundance, size or other qualities (Turner *et al.* 2011b). Plant resilience to harvest may depend on multiple factors including local climatic conditions (Gaoue & Ticktin 2010), plant part harvested (Ticktin 2004), and co-occurring disturbances (Martínez-Ramos, Anten & Ackerly 2009; Mandle & Ticktin 2012). Resilience can also depend on the harvest pressure or intensity (Lopez-Toledo *et al.* 2012), which can vary depending on the relationship of a group of people harvesting to the target plant species (Berkes, Folke & Gadgil 1994). Past estimates suggest 4-6 thousand plants species are wild-harvested from forests globally (Ticktin 2004). Understanding the co-occurring and potentially interacting effects of harvest, fire and abiotic factors is key to protecting the ecological and cultural services provided by wild-harvested plants (Chamberlain *et al.* 2018).

Though NTFP harvest may reduce population growth (Schmidt *et al.* 2011), interactions of harvest with other factors are likely important for describing sustainability (e.g., Souther & Mcgraw 2014), but have rarely been described. I was able to identify only two studies that described interactions between non-timber forest product harvest and fire in relation to plant demography. A study on the mountain date palm (*Phoenix loureii*), found that plants in burned areas were more resilient to an equal proportion of leaf harvest, perhaps because plants in burned areas had more leaves (Mandle & Ticktin 2012). Another study on candombá (*Vellozia* aff. *sincorana*) found that harvest was only sustainable in the presence of fire (Souza *et al.* 2018). For plants that are adapted to fire, I would expect that fire would reduce the negative impacts of harvest on plant survival, growth and/or reproduction.

Fire alters understory biophysical conditions and may also influence the relationship of these biophysical conditions to plant demography. Fire can reduce or remove the forest litter layer, increase the amount of light reaching the forest floor, and increase available soil nitrogen (ammonium and nitrate) (Boerner 1982; Wan, Hui & Luo 2001). Removal of the organic soil horizon generally promotes seedling establishment because seedling roots can penetrate the mineral soil, but at low moisture levels, the lack of litter layer may increase seedling exposure to desiccating conditions (Holmgren, Scheffer & Huston 1997; Albrecht & McCarthy 2009). A study in wet sclerophyll forest in Australia found that water stress in the post-fire environment led to greater seedling mortality than in unburned areas (Campbell, Keith & Clarke 2016). Fire may also interact with soil moisture to influence plant growth. A study in temperate deciduous forest found that soil moisture increased plant growth in areas that were burned, but not in unburned areas, which the authors attributed to other factors that limited growth in the absence of fire (Wagner & Fraterrigo 2015).

The season or timing of a fire can influence its impact on plant demography and community structure (Biondini, Steuter & Grygiel 1989; Brewer & Platt 1994; Gillespie & Allen 2004; Emery & Gross 2005) and can also influence fire severity (Knapp *et al.* 2007). As these papers describe, fires in different seasons impact plants at different points across their life cycle and may differentially influence processes such as seedling recruitment and herbivory. The timing of fire can also influence fire severity given seasonal differences in soil moisture, fuel moisture and weather conditions (Littell *et al.* 2016). However, a review paper on prescribed fire in contemporary western ecosystems suggests fuel accumulation is more important in determining impacts of fire on vegetation than fire season (Knapp, Estes & Skinner 2009). Native Americans use and have used fire carefully and intentionally across different seasons and in different areas for different purposes (Stewart 2002; Turner *et al.* 2011a; Lake *et al.* 2017). In some cases, low severity traditional fires may have been achieved in part by timing the fire to occur close to or at the onset of the rainy season. At this time, vegetation may have the right moisture levels for the fire to achieve desired effects (Anderson 1996; Turner 1999; Eriksen & Hankins 2014).

Beargrass, *Xerophyllum tenax* (Pursh) Nutt. Melanthiaceae, is a culturally and economically important understory herb, well-suited to a study of responses to fire, abiotic factors and harvest. Beargrass occurs on cold, seasonally-dry and nutrient-poor sites in the Cascade Mountains between 600 and 2200 m (Hummel *et al.* 2012; Peter *et al.* 2017). It is also found more sparsely in lowland areas from Northern California to the Olympic Peninsula of Washington, and from Wyoming to Canada along the Rocky Mountains (Hummel *et al.* 2012). Populations in mid to high elevation areas in the Cascades are seasonally covered by snowpack and soil moisture declines over the dry summer growing season. Beargrass is considered fire-adapted in the sense that beargrass populations anecdotally increase flowering (Maule 1959) and re-sprout from rhizomes after fire (Shebitz *et al.* 2008; Hummel *et al.* 2012), and because its seeds may germinate more readily after exposure to smoke-infused water (Shebitz *et al.* 2009a). Beargrass' durable and pliable leaves are harvested by Native Americans for basketry and other purposes (Hummel & Lake 2015). It is also a multi-million US dollar non-timber forest product that is harvested and sold as a floral green (Thomas & Schumann 1993). Beargrass is utilized for food, habitat and/or nesting material by bears (*Ursus americanus and U. arctos*), elk (*Cervus canadensis* ssp. *rooseveltii* and *C. canadensis* spp. *nelsoni*), deer (*Odocoileus hemionus* and *O. virginianus*) and a variety of small mammals and insects (Hummel *et al.* 2012).

Beargrass has decreased in range and local abundance in some regions likely due to fire suppression and commercial harvest (Peter & Shebitz 2006; Shebitz *et al.* 2008). Cultural practitioners have reported that it is becoming more difficult to find (Levy 2005; Shebitz 2005; Shebitz *et al.* 2009b; this dissertation). The issue is not only quantity of plants, but quality (Shebitz 2005). Most weavers prefer leaf qualities which are promoted by recent fire, traditionally a part of Native American forest stewardship (Rentz 2003; Hummel & Lake 2015), but these are increasingly hard to find.

In this study, I investigate how fire severity, abiotic conditions and leaf harvest influence beargrass demography. I specifically ask how beargrass vital rates (growth, survival and reproduction), vary with fire severity and how fire severity may interact with soil moisture and leaf harvest to influence beargrass demography. I hypothesized that fire would increase growth (Abrahamson 1999), flowering (Abrahamson 1999; Bourg, Gill & McShea 2015; Mandle *et al.* 2015a) and vegetative reproduction (Menges & Root 2004) (Hypothesis 1A), and that survival would be reduced with high severity fire because traditional fire management typically involves low severity fire (Hummel *et al.* 2012) (Hypothesis 1B). Secondly, I also hypothesized that soil moisture would increase survival, flowering and growth, and that this growth rate increase would be greatest in burned areas (Wagner & Fraterrigo 2015) (Hypothesis 2). Thirdly, I hypothesized that leaf harvest would have a negative effect on growth and flowering (Flores & Ashton 2000; Martínez-Ramos *et al.* 2009; Gaoue & Ticktin 2010) and a positive effect on vegetative reproduction (Schmidt, Figueiredo & Scariot 2007) (Hypothesis 3). Lastly, I hypothesized that responses to harvest would depend on fire severity, with fire reducing the negative effects of harvest on growth (Mandle & Ticktin 2012) (Hypothesis 4). Disentangling effects of disturbance, light and soil moisture on beargrass demography can provide management recommendations for increasing the availability of flowers and leaves for cultural and ecological ecosystem services such as pollen rewards for insects, winter forage for large mammals, and materials for perpetuation of basketry traditions among Native Americans. This study can also provide insights on how beargrass and potentially other fire-adapted plants may respond to changes to seasonal soil moisture conditions or to fire regimes.

Methods

Study species

Beargrass is a perennial herb that reproduces both sexually through seed and asexually through tuber-like rhizomes (Hummel *et al.* 2012)(Fig. 3.1A & 3.1E). Beargrass individuals are monocarpic, though genets persist after flowering (Peter *et al.* 2017). Beargrass is mass-flowering and mostly self-incompatible with a racemose-paniculate inflorescence (Vance *et al.* 2004). While some individuals flower every year (pers. observ.), mass flowering occurs on irregular cycles that are poorly understood (Meyers *et al.* 2015). Flowering in this study was followed by vegetative reproduction of new shoots adjacent to the flowering stalk (Fig 3.1E), similar to as reported for confamilial

Veratrum album (Hesse, Rees & Müller-Schärer 2008). Leaves form a rosette similar in appearance to a grass and are tough and wiry. In this study, individuals were covered in snow in the winter and spring, and snowmelt occurred in April or May. Beargrass was the most abundant understory plant or was co-dominant with huckleberry (primarily *Vaccinium membraceum*) (Appendix 3.1-A).

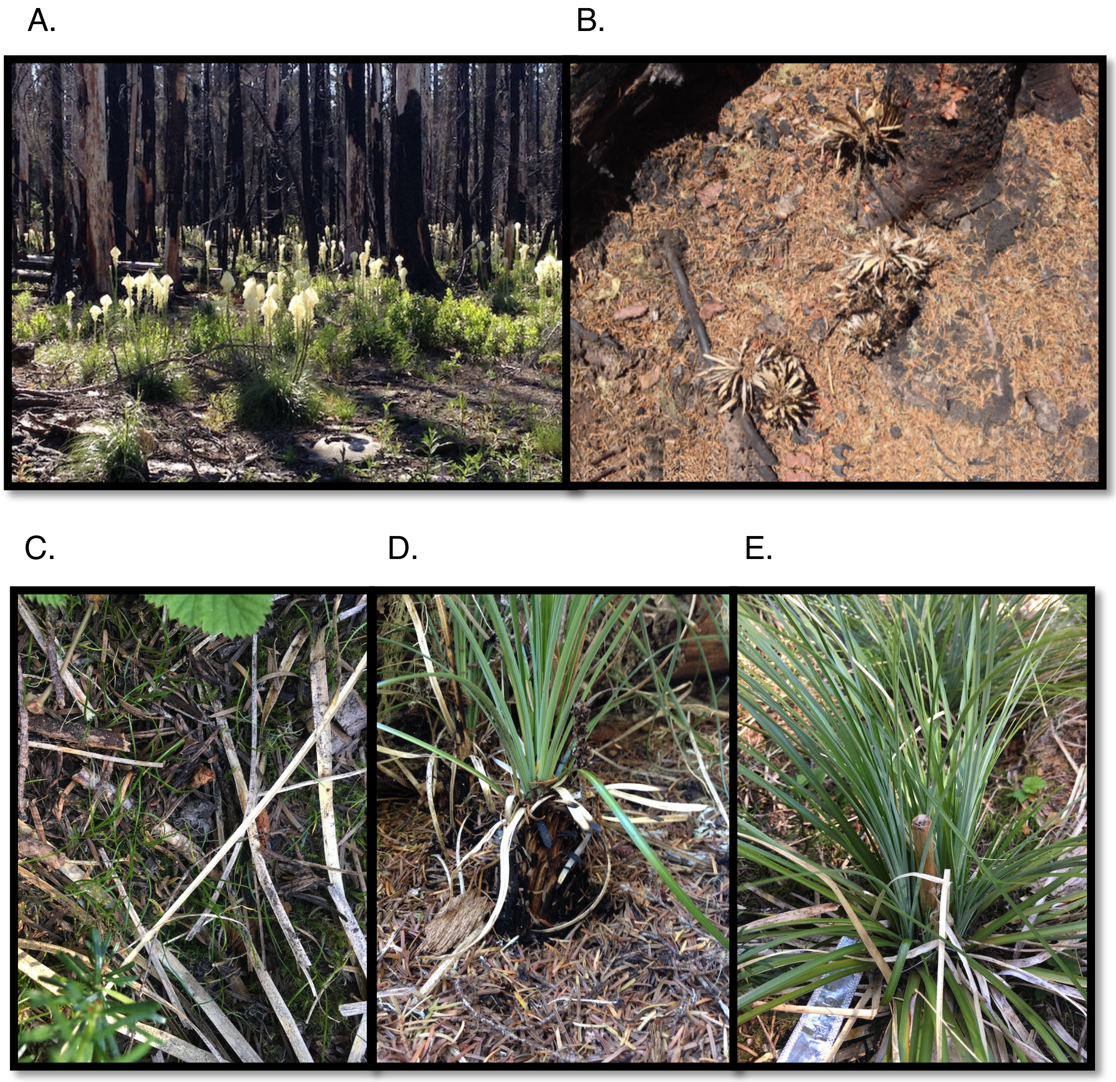


Figure 3.1. Images of beargrass across its life cycle. (A) beargrass mass flowering three years after a wildfire, (B) charred remains of beargrass individuals in a high-severity area one year after wildfire, (C) seedling recruitment in an unburned area in 2016, (D) a beargrass individual with fire damage on basal leaves, and (E) vegetative reproduction of new ramets by an individual that flowered the previous year. The old flower stalk is visible.

Site selection

To test the effect of fire severity and other drivers on beargrass vital rates, I surveyed wildfires that occurred in 2014 on the Mount Hood National Forest in Oregon that were at least 0.4 hectares and had at least 1000 beargrass individuals. I selected the first three sites that met these requirements. These sites occurred in the Pacific Silver Fir (*Abies amabilis*) Zone (Hemstrom *et al.* 1982; Henderson 2009), between 1160 and 1340 meters elevation and were each separated by at least three kilometers (Table 3.1). This vegetation zone is characterized by cool temperatures, nutrient poor and shallow soils, a relatively short and dry growing season and heavy precipitation primarily as winter snowpack between 2-4 m (Franklin & Dyrness 1973; Hemstrom *et al.* 1982). At our sites, all fires were lightning ignitions between July and September, extinguished by fire crews with a fire line and water (Table 3.1). Fires resulted in complete tree mortality and canopy loss across a major portion of each fire. *Abies amabilis* is a climax species with high shade and drought tolerance, but low fire tolerance (Greir *et al.* 1981; Hemstrom *et al.* 1982). Fire return intervals are variable in this vegetation zone, but fire history studies typically report infrequent and high severity natural fire regimes (Hemstrom 1979; Reilly *et al.* 2017). Soils across all three sites were silt loams (assessed onsite by USFS Mt. Hood National Park soil scientist Tom Reinwald).

Table 3.1. Characteristics of study sites

Site	Date of wildfire discovery	Size of fire (hectares)	Elevation (m)
Site A	7/16/2014	2.02	1340
Site B	9/17/2014	0.93	1160
Site C	7/16/2014	12.14	1220

Plot selection

Myself and field assistants established three 4 x 4 meter plots within each site: one subject to high severity fire, one to low severity fire, and one unburned. Plot locations were determined using a stratified random approach. I selected random locations from areas with 20-45% slope, south, east or southeast aspect, and at least 10% beargrass cover which also met the fire severity criteria. High severity areas had near 100% mortality of trees, and beargrass individuals that were partially or fully blackened with lower leaves burned off (Fig 3.1D). This was the most common fire severity observed. Low severity areas had < 50% tree mortality, moss visible but singed brown, and beargrass individuals with leaves singed to a white color, but not blackened or burned off. Unburned areas were located at least 14 m from the fire line (Appendix 3.1-B). Though not visually apparent, fire suppression activities such as walking through or dragging a hose through the study sites could have impacted vegetation cover, such as moss cover, in study plots. At site B, a few dead trees were cut within the fire. Though cut trees were more than 10 m from our plots, their removal would have slightly increased canopy openness values in our study. Vegetative composition was measured in each plot one and three years post-fire. Across all fire severities, understory percent cover by vertical projection one year after the fire consisted of 15-60% beargrass, 0-75% *Vaccinium* spp., 0-95% moss, and 0-20% conifer seedlings and saplings, particularly pacific silver fir (*Abies amabilis*), mountain hemlock (*Tsuga mertensiana*) and western hemlock (*Tsuga heterophylla*). See Appendix 3.1-A for more detailed vegetation information. All beargrass individuals within each plot were numbered and tagged. Because beargrass reproduces both sexually and asexually and I could not determine the genetic relationship between all plants in the study, I refer to plants as 'individuals.' I use the word 'ramet' for individuals known to be produced through vegetative reproduction. Ramets are genetically identical to other individuals in a clonal colony, or genet.

Demographic measurements

In late July or early August of 2015, 2016 and 2017, demographic measurements were taken on all individuals. I did not measure individuals in the year of the fire (2014) and therefore survival in 2015 is estimated from charred individual remains (Fig. 3.1B). Basal diameter was used as a measure of individual size (Appendix 3.1-C) and was measured in millimeters (mm) with digital calipers at the individual base excluding dead leaves. Leaves were held and compressed for size measurements. Individuals were considered dead if they had no green tissue for two consecutive years. Sexual reproduction was recorded through the presence of flowering stalks. If inflorescences had not fully formed their seed capsules at the time of census, which was uncommon, pedicels were counted instead. When flowering stalks were broken, I estimated seed capsule production from the relationship of individual size measures to seed capsule production calculated in a separate substudy (Appendix 3.1-D). Vegetative reproduction was determined by presence of a new ramet adjacent to another individual (Fig. 3.1E).

Abiotic measurements

Canopy openness was estimated from a hemispheric photograph taken at 0.5 m from the ground surface above each beargrass individual (Rich 1990; Jennings, Brown & Sheil 1999). I took separate photos for individuals that were separated by 8 cm or more. Gap Light Analyzer Software Version 2 was used to analyze photographs applying a blue color filter and 110 contrast within the software program prior to calculating canopy openness (https://www.sfu.ca/rem/forestry/downloads/gap-light-analyzer.html). All pictures were captured in 2016 or 2017 before sunrise, after sundown, or on cloudy days to avoid calculation errors caused by sunlight reflecting off vegetation. Soil moisture was measured adjacent to each individual using a handheld probe with digital readout that measures average volumetric water content in the top 12 cm of the soil (Hydrosense II, Campbell Scientific). Measurements were taken across all sites (between 6:00 and 18:00 hours) within a five-day period to facilitate comparison across sites and plots. I avoided midday measurements when possible (between 12:00 and 2:30 PM) to minimize the influence of diurnal soil moisture changes in our data (Moore, Jones & Bond 2011) (Appendix 3.5-A & 3.5-B). I took the average of three measurements equally spaced around each individual in 2016. Measurements were taken as close to the individual as possible, evenly spaced around that individual, while avoiding rocks in the soil that prevented the probe from being fully inserted. For ramets that were within another individual, measurements were taken next to the ramet just outside the leaf base of the individual that produced the ramet. Measurements were taken twice per field season (late May/early June and late July/early August), to capture the relative differences at different points across the growing season. In 2017, I took one measurement per individual in each season due to time constraints. Soil moisture measurements taken in 2015 are not included in our study because a different soil moisture probe was used in that year did not provide reliable readings.

Leaf harvest treatment

In late July of 2016, I conducted a leaf harvest experiment, simulating one technique used by northwest Native American beargrass gatherers. The timing of this experiment overlapped with traditional practice (pers. comm. indigenous beargrass weavers in Oregon). Twenty harvest-quality (>20cm basal diameter, non-flowering) individuals were randomly selected per plot and ten leaves were plucked from the inner-middle portion of the individual. These were the youngest mature leaves (Rentz 2003). The number of individuals harvested (no more than 20% in a given area) matched one documented practice (Baldy 2013).

A summary of recorded predictors used in the models for the overall study is given in Table 3.2. Flowering was included as a predictor in the vegetative reproduction model because I observed that vegetative reproduction always accompanied flowering, though vegetative reproduction also occurred without flowering. Because flowering individuals produced new ramets the year of or the year following flowering, flowering in this model refers to the current or previous year.

Table 3.2. Management and abiotic drivers used as predictors of vital rates

Predictors	Data type and description	Interpretation/purpose
Management		
Fire severity	Categorical: High severity, low severity and unburned	Impacts of fire and changes to fire severity
Harvest	Binary: harvest or no harvest	Impacts of beargrass leaf harvest for use in basket making
Abiotic		
Early season soil moisture	Numeric: soil moisture in late May/early June	Available moisture to individuals shortly after snowmelt
Late season soil moisture	Numeric: soil moisture in late July/early August	Available moisture to individuals later in the growing season
Canopy openness	Numeric: 0-100%	Impacts of light and possible indirect effect of fire
Demographic		
Flowering	Binary: flowered or did not flower in the current year or previous year	Impacts of flowering on vegetative reproduction (vegetative reproduction models only)

Data analysis

I used general and generalized linear mixed models (GLMs and GLMMs) to assess the relationship of fire severity and its interactions with leaf harvest, flowering, and soil moisture to beargrass vital rates. Plot within site was included in the random effects structure of all models to account for the study design: plots were spatially nested within sites and individuals were located within specific plots (Barr *et al.* 2013). I constructed vital rate models separately for each year-since-fire except in the case of the number of ramets vegetatively produced, where I combined the 2016 and 2017 data due to low sample size. For this model, I therefore also included year as crossed random factor. Because beargrass individuals are monocarpic, flowering is perfectly correlated with mortality. In order to assess non-flowering causes of mortality, survival models did not include individuals that flowered. Individuals that flowered in year *t* were omitted from survival models for that year (i.e., they were not included in year *t*-1). There was not sufficient representation of seed capsule production data across plots and sites to build a seed capsule production model while retaining the random effects structure. I therefore report the mean and standard deviation of capsule production per flowering stalk.

While seedlings did recruit during the study, I did not include seedlings the vital rate models because I did not have sufficient representation of seedlings across the levels of the random effects (sites and plots) (Appendix 3.2-G). In 2016, there were a large number of seedlings (>1,500) in our census with more than 90% having recruiting to the unburned and low severity plots at site C (Fig 3.1C). In comparison, there were less than 10 seedlings present in 2015. Seedlings are influenced differently than non-seedlings by environmental factors such as soil moisture (Pinto *et al.* 2016), and I did not have the spatial representation of seedlings to distinguish between site-specific effects and effects of the environmental factors of interest. In excluding seedlings from the models, I defined seedlings as individuals less than 3 mm basal diameter that were not within another individual (i.e., not ramets). New vegetative ramets were sometimes less than 3 mm but were distinguished by their adherence to another individual.

Lack of data from 2014 limited my ability to assess some vital rates in 2015. Survival and sexual reproduction models are reported for 2015, but vegetative reproduction for 2015 is not reported as I could not distinguish between vegetative ramets that emerged the year I monitored and those that had emerged in years past. For the 2015 survival and flowering models, size of individuals in 2015 was used a proxy for individual size in 2014 because demographic data was not collected in 2014. I also tested the effect of estimating 2014 size by subtracting the average growth rate of individuals from 2015-2016 from individual sizes in 2015. There was no meaningful difference in the predictions from these two approaches, and I therefore used 2015 individual size to model 2015 survival and flowering.

To the extent possible, I included all relevant main effects and two-way interactions with size and fire severity in the full models. Some factors were not tested in specific models because of sample size limitations, lack of data overlap, or lack of relevance. These exclusions are described in the paragraph below, are specified in Table 3.3, and are included below regression tables in Appendix 3.2.

I did not consider the interaction of fire severity with canopy openness in any of the models because of insufficient overlap in canopy openness values between burned and unburned plots (as little as 10% overlap, Appendix 3.4). Soil moisture was not used in models that included 2015 data as soil moisture was not measured in 2015. Due to the small number of non-seedling individuals that died during the study, only interactions with size, but not fire severity were considered in the survival models. Soil moisture measurements were also not included for the 2016 survival model as measurements were not taken on a majority of the individuals that died. I did not explore interactions with fire severity in the flowering model in 2016 because only 14 individuals flowered. The number vegetative ramets model did not include interactions with fire severity, again, due to sample size. Late soil moisture was not used as a predictor of flowering, vegetative reproduction or number of ramets produced, as it was measured after individuals had flowered and/or vegetatively reproduced.

Starting with the full models including all main effects and interactions apart from those mentioned above, I sequentially removed least significant terms, selecting the best-supported models with AIC (Zuur *et al.* 2009). Survival, flowering and vegetative reproduction were modeled with a binomial (Bernoulli) distribution. Growth was modeled with a Gaussian distribution. The number of ramets vegetatively reproduced was initially modeled with a Poisson distribution. The fit of initial and best-supported LMMs to data was assessed by plotting quantile-quantile plots and plotting fitted values and predictors against the standardized residuals (Zuur *et al.* 2009). The fit of initial and best-supported GLMMs to data were assessed with the DHAMRa package (version 0.2.4) (Hartig 2019). This package simulates scaled residuals that can be interpreted similar to residuals from linear regression. Using this package, I plotted the predictors against the scaled residuals with the plotResiduals function to diagnose potential sources of heteroscedasticity. I also tested model residuals for uniformity, dispersion and for outliers with the testResiduals function. Cases where model assumptions were not met are discussed below. Models were built in R using the glmmADMB (version 0.8.3.3), glmmTMB (version 0.2.3), lme4 (version 1.1.19), and nlme (version 3.1.137) packages (Fournier *et al.* 2012; Bates *et al.* 2015; Brooks *et al.* 2017; Pinheiro *et al.* 2018; R Development Core Team 2018).

Both LMMs exhibited some degree of heteroscedasticity. Residual variance in the growth models decreased with individual size. Residual variance in the 2016-2017 growth model also varied by study site. To address this heteroscedasticity I tested the influence of adding variance covariates to these models, selecting the optimal covariance structure with AIC (Zuur *et al.* 2009). The exponential by size (2015-2016) and exponential by size with site (2016-2017) variance covariates were added to the growth models. Subsequent checks of model residuals showed close conformity with model assumptions.

Ten of twelve GLMMs met assumptions of uniformity, close conformity with homogeneity of variances and appropriate dispersion. However, the flowering in 2015 model had increasing residual variance with individual size. Removing the two largest ramets in the model greatly reduced this heteroscedasticity, but had little impact on parameter estimates, and I therefore proceeded with the model, retaining these two largest individuals. The model for the number of ramets produced was underdispersed, and I therefore modeled the number of ramets produced with the Conway-Maxwell-Poisson distribution in the glmmTMB package (Brooks *et al.* 2017).

I assessed the collinearity of predictors in initial and best-supported models and also calculated pseudo R^2 values for the best-supported models. All models were checked for collinearity by evaluating their variance inflation factors (VIF) using the car package in R (Fox & Weisberg 2011). All predictors in all models has VIFs less than 1.13. Pseudo R^2 values are reported for all models in Appendix 3.2-F. The concept of R^2 in fixed effects models is not easily extrapolated into the mixed effects models environment (Bolker 2008). To give the reader an idea of the variance explained by the models, I calculated pseudo R^2 in two ways. I first used the MuMIn package (version 1.42.1) in R to calculate marginal and conditional R^2_{GLMM} values for all models (Bartoń 2018). I report the trigamma estimate when available (number of vegetative ramets produced model only), and the delta estimates otherwise. Secondly, I report a simple pseudo R^2 value as the correlation between observed and fitted values (Appendix 3.2-F).

I plotted models and specific interactions with different approaches depending on the model error structure, model complexity, and the types of predictors included in the model. For Gaussian models (growth models), lines in figures are model predictions holding fixed factors at their median values, and points are the same predicted values plus full model residuals. Because binomial data includes only zeros and ones, which are difficult to interpret visually, binomial models (survival, flowering and vegetative reproduction) were plotted by taking the average response probabilities and covariate values across intervals of x-axis values (i.e., size). I used the maximum number of intervals that allowed for at least 10 individuals to be represented by each plotted point. Because of the spread of data across individual size, points included as many as 161 individuals. Lines in these plots are model predictions with the same mean covariate values by size interval. Separate points and lines were plotted by fire-severity class when fire-severity was included in the best-supported model. In the probability of vegetative reproduction model, the interaction of interest was between a binary (flowering) and categorical (fire-severity) factor. To plot this interaction, I held other factors in the model at their median values and leaf harvest at zero, and then plotted a double bar graph of vegetative reproduction probability by fire-severity class and flowering status. Given the simplicity of the number of vegetative ramets model (Conway-Maxwell-Poisson distribution), which only included size and flowering, I plotted each individual as a point and lines as model predictions by size with and without flowering.

Results

Fire influenced every aspect of beargrass' life cycle tested in every year sampled, with exception of the number of ramets vegetatively produced and survival and flowering three years post-fire. As predicted, fire increased all beargrass vital rates that it influenced, except for survival one and two years post-fire. Fire also mediated the effects of soil moisture and flowering on beargrass demography and these effects differed with time-since-fire. The effects of fire severity did not interact with the effects of leaf harvest to influence any part of the beargrass life cycle.

Survival

Non-seedlings had high survival rates: 93.6% one year post-fire, 96.2% two years post-fire and 98.6% three years post-fire. Survival was much lower for the large cohort of seedlings that established in 2016 (55.7% three years post-fire; Figs 3.2A & 3.2B). One and two years following fire, survival was higher in unburned than in burned plots and survival decreased with fire severity (Table 3.3, Appendix 3.2-A & 3.2-F) (H1B), but the coefficient of determination of the survival models was much greater one year ($R^2_{GLMM(c)}$ = 0.798), than two years post-fire ($R^2_{GLMM(c)}$ = 0.024), likely because only nine individuals died two years post-fire. Three years post-fire, the best-supported model included the interactions of canopy openness with size and leaf harvest with size, but the coefficient of determination for this model was low ($R^2_{GLMM(c)}$ = 0.033, Table 3). Three years post-fire, 19 of 30 non-seedling mortalities were small individuals in unburned areas. Contrary to expectation, survival did not vary with soil moisture (H2).

Though I did not anticipate any effect, leaf harvest decreased survival probability in individuals of harvestable size (> 17 mm basal diameter). With other factors held at their median value, survival was reduced with leaf harvest by ~0.3 percentage points for an individual of mean harvestable size (30 mm) and by 13 percentage points for an individual with a 50 mm basal diameter. The reduction in survival probability was greatest in unburned plots, but there was not sufficient sample size to test this interaction in the model.

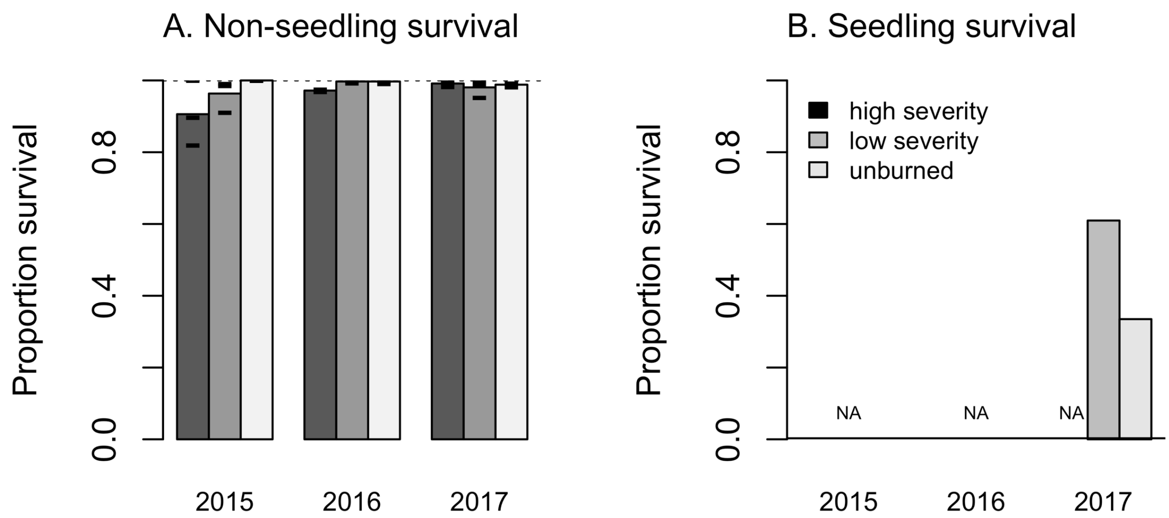


Figure 3.2. Probability of survival was lower for seedlings than non-seedlings. (A) Proportion non-seedling survival with dashes indicating site-level variation. (B) Seedling survival without error bars because > 90% of seedlings were found at a single site (Appendix S1-E). Fewer than five seedlings were present in 2015 or 2016, or in high-severity plots in 2017.

Table 3.3. Predictor variables in optimal regression models selected by AIC.

Response variable	Predictor variables in best model*	Interactions in optimal model	Predictors and interactions not tested**	Sample size†	Model df	Marginal $R^{2††}$
Survival						
2015	<u>fire</u>, <u>size</u>, canopy	canopy and size	soil moisture, fire and canopy, fire and size	929	8	0.7831
2016	fire, **size**		soil moisture, fire and canopy, fire and size	858	6	0.0241
2017	size, canopy, harvest	canopy and size, harvest and size	fire and canopy, fire and size, fire and harvest, fire and soil moisture	1130	8	0.0333
Growth						
2015-2016	fire, size	fire and size	fire and canopy	848	10	0.1769
2016-2017	fire, size, early soil moisture	early soil moisture and size, fire and early soil moisture	fire and canopy	1114	14	0.3638

Table 3.3 (Continued). Predictor variables in optimal regression models selected by AIC.

Response variable	Predictor variables in best model*	Interactions in optimal model	Predictors and interactions not tested**	Sample size†	Model df	Marginal R^2††
Flowering						
2015	**fire**, **size**		soil moisture, fire and canopy	790	6	0.3651
2016	**fire**, **size**		late soil moisture, all fire interactions	886	6	0.283^
2017	**size**, **canopy**		late soil moisture, fire and canopy	930	5	0.2305
Vegetative Reproduction						
2016	fire, size, **flowering**	fire and size	late soil moisture, fire and canopy	876	9	0.2009
2017	fire, size, **harvest**, **flowering**	fire and flowering, flowering and size	late soil moisture, fire and canopy	1127	11	0.4498
Number of vegetative ramets						
2016 and 2017	**size**, **flowering**		late soil moisture, all fire and size interactions	216	7	0.0751

Table 3.3 (Continued). Predictor variables in optimal regression models selected by AIC.

*Bolded variables are those that had a consistently positive effect. Underlined variables had a consistently negative effect. The effects of unmarked predictors vary from positive to negative depending on interacting terms, and/or in the case of fire, on fire severity (Appendix 3.3 A-E).

**Some factors were not tested in specific models because of limitations in sample size, lack of data overlap, outlier effects, or lack of relevance (see Methods: Data analysis).

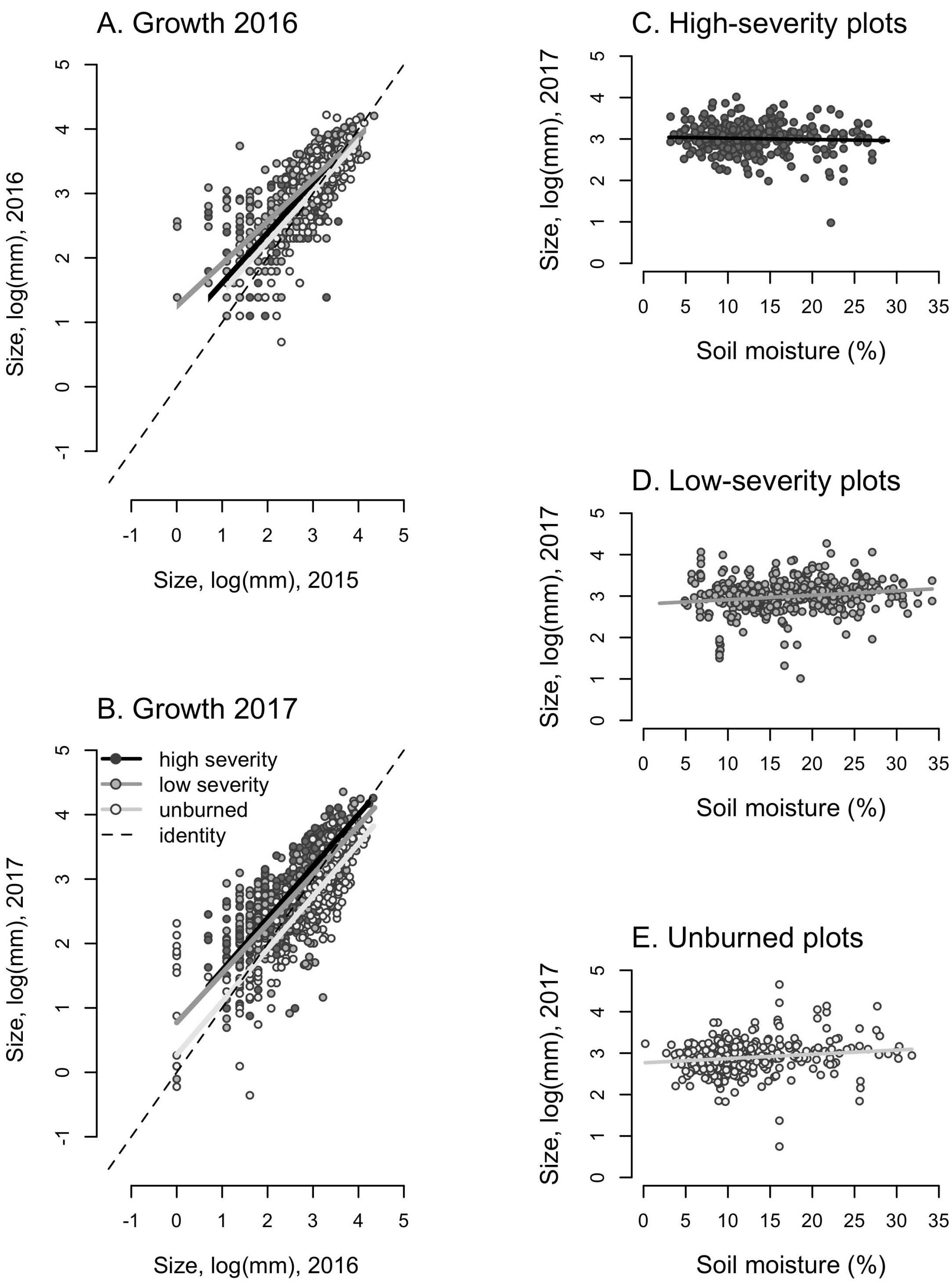
†Sample size refers to the number of individuals included in each model and varied by year due to recruitment and mortality. For the number of vegetative ramets models, sample size was limited by the number of individuals that reproduced. Only individuals with complete data for all covariates in a given model were included.

††Marginal pseudo R^2 (variance explained by fixed effects) calculated using the MuMin package in R (see Appendix 3.3-F).

^Very few individuals flowered in 2016 and therefore a R^2 value could not be calculated with MuMin. Instead, I report the correlation of fixed and observed values for this model (see Appendix 3.3-F for details).

Growth

As predicted (H1), growth was consistently higher in burned than in unburned plots. Two years post-fire, for an individual of mean size (17 mm basal diameter), growth was 15% greater in high-severity plots and 25% greater in low-severity plots than in unburned plots. Three years post-fire, for an individual of mean size (20 mm basal diameter) and with other factors at their mean value, growth was 30% higher in low-severity and 44% higher in high-severity than in unburned plots. The one to two years post-fire model had a lower coefficient of determination ($R^2_{GLMM(c)}$ = 0.180) than the two to three years post-fire model ($R^2_{GLMM(c)}$ = 0.384) (Appendix 3.2-F). Growth decreased with individual size (Figs 3.3A & 3.3B, Table 3.3). In contrast to the predicted interaction between soil moisture and fire (H2), two to three years post-fire, early season soil moisture increased growth more in unburned and low-severity fire plots than in high-severity fire plots (Fig 3.3C-E, Table 3.3). Contrary to prediction (H3 and H4), individual growth did not vary with leaf harvest.



A. Growth 2016
Size, log(mm), 2016
Size, log(mm), 2015
B. Growth 2017
high severity
low severity
unburned
identity
Size, log(mm), 2017
Size, log(mm), 2016
C. High-severity plots
D. Low-severity plots
E. Unburned plots
Size, log(mm), 2017
Soil moisture (%)

Figure 3.3. Individuals grew more in burned than unburned plots and the relationship of soil moisture to growth varied with fire severity. Final size (basal diameter) of individuals is shown in the second (A) and third years (B) following fire given their size the previous year. Dotted line is the identity line, or line of zero growth for an individual. Predictors other than size are plotted at their median values by fire-severity class. Panels (C-E) show growth increasing with early season soil moisture in unburned and low-severity fire plots, but not in high-severity fire plots from two to three years post-fire. Lines are model predictions plotted holding other fixed effects in the model at their median values by fire severity. Points are model predictions plus full model residuals.

Sexual reproduction

As predicted (H1), flowering increased with fire severity one and two years post-fire (Figs 3.4A, 3.3C, & 3.3D, Table 3.3, Appendix 3.2-C). The 2015 flowering model described more variation in flowering ($R^2_{GLMM(c)}$ = 0.582) than the 2017 model ($R^2_{GLMM(c)}$ = 0.295). The 2016 flowering model coefficient of determination could not be calculated as there was not enough flowering to parameterize the null model (Appendix 3.2-F). Mass flowering occurred at sites B and C in 2015 and at site A in 2017 (Fig 3.1A & 3.4B). Across the study sites, beargrass occurred in tight clumps of two to thirty ramets, such that a 10% individual flowering rate reflects a much higher genet flowering rate. Three years post-fire, flowering was better described by canopy openness than fire severity (Appendix 3.2-C). No individuals flowered in the unburned plots either two or three years post-fire. In all years, flowering probability increased with individual size (Figs 3.4C-E). Contrary to my predictions (H3), flowering probability did not vary with leaf harvest. I observed a mean of 187 (std. dev. 77.2) and a maximum of 400 seed capsules per inflorescence in the study plots (n=61 individuals).

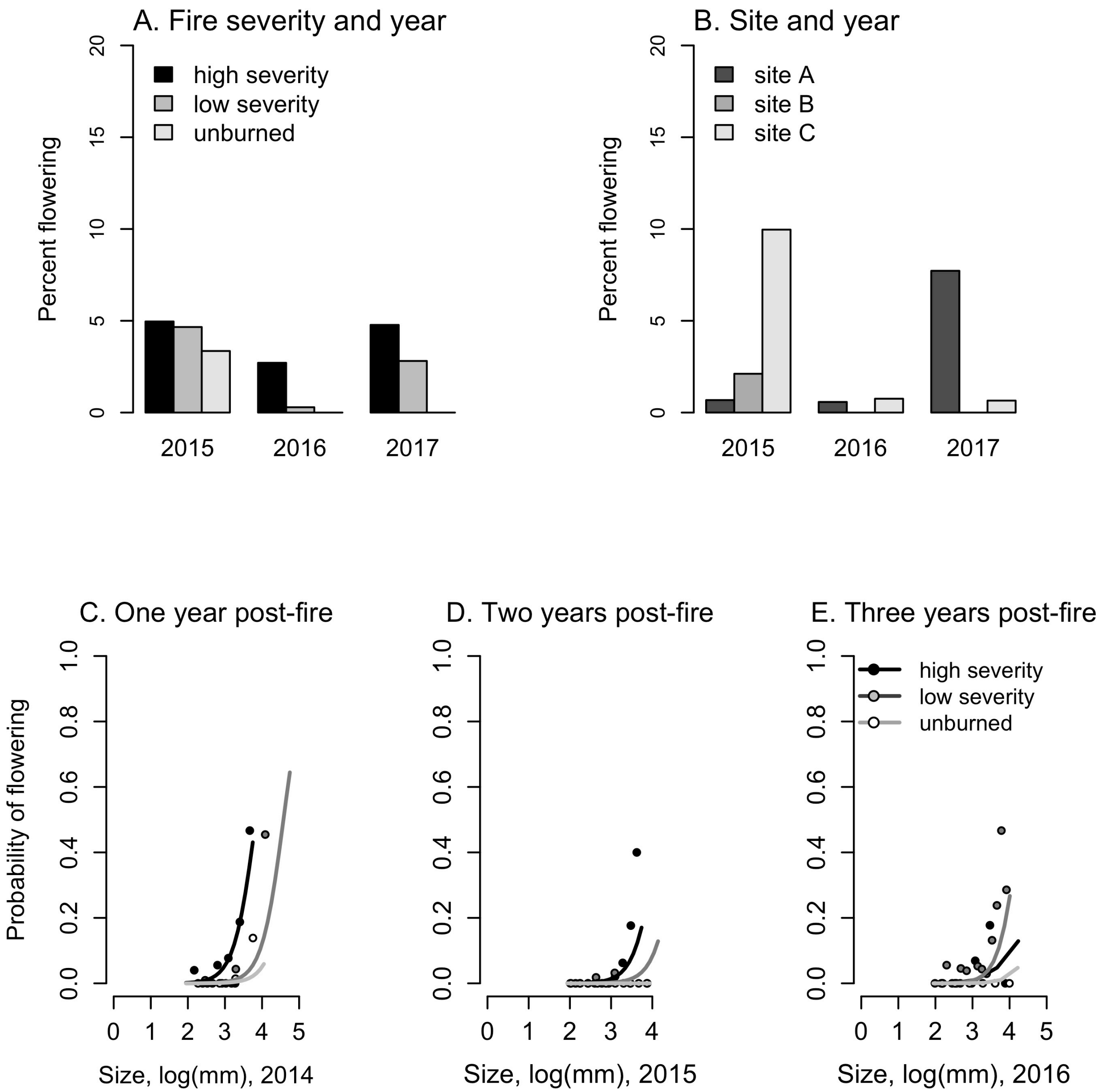


Figure 3.4. Individual flowering increased with size and with fire. Percent of individuals (> 6 mm basal diameter, the smallest size observed to flower) flowering by fire severity and year (A), and by site and year (B). Flowering probability by fire severity and size the previous year in 2015 (C), 2016 (D) and 2017 (E). Points are mean flowering probability within a size interval with each interval containing 10-161 individuals. Lines are model predictions with other factors in the model at held at their mean value by fire severity (see Methods section, Data analysis).

Vegetative reproduction

Beargrass individuals died after flowering, and asexual reproduction always accompanied flowering. In this study, one to seven new beargrass ramets emerged from lateral buds adjacent to the flowering stalk beginning the year of or the year following flowering. Vegetative reproduction also occurred without flowering in both burned and unburned populations. Vegetative reproduction was observed in individuals subject to between 13 and 76% canopy openness.

In support of my first hypothesis (H1A), the proportion of individuals that vegetatively reproduced was higher in burned than unburned areas (Fig 3.5A, 3.5C & 3.5D, Appendix 3.2-D). Vegetative reproduction was also higher three years than two years post-fire (Fig 3.5A & 3.5B). The model three years post-fire explained more variance in vegetative reproduction ($R^2_{GLMM(c)}$ = 0.548), than two years post-fire ($R^2_{GLMM(c)}$ = 0.258, Appendix 3.2-F). The effect of fire on the probability of vegetative reproduction was more nuanced than expected (H1A). Though the probability of vegetative reproduction was always higher in burned than unburned plots, two years post-fire, the fire severity with the highest probability of vegetative reproduction depended on individual size (Figs 3.5C & 3.5D, Appendix 3.2-D & 3.2-F).

As predicted (H3), leaf harvest increased vegetative reproduction. For an individual of mean harvestable size (~31 mm basal diameter) that did not flower, leaf harvest increased the probability of vegetative reproduction from 0.3% to 1% in unburned plots, from 13% to 25% in low-severity plots and from 42% to 61% in high-severity plots. For an individual that did flower, probabilities of vegetative reproduction increased with leaf harvest from 30% to 48% in unburned plots, from 82% to 91% in low-severity plots and from 29% to 47% in high-severity plots.

Vegetative reproduction probability in a given year increased when the individual had flowered in the current or previous year. Two years post-fire, for an individual of mean size (20 mm basal diameter), flowering increased the probability of vegetative reproduction across all fire severities with the smallest increase in low-severity plots (i.e., from 16%-64%, from ~0%-2% and from 7%-63% in unburned, low-severity and high-severity plots, respectively). Three years post-fire, the positive effect of flowering on vegetative reproduction decreased with individual size and decreased with fire severity (unburned > low severity > high severity) (Fig 3.5E, Appendix 3.2-D).

The number of ramets vegetatively produced per existing individual varied from one to seven in a given year, increased with individual size, and was greater for individuals that had flowered (Table 3.3, Fig 3.5F, Appendices S2-E). The majority of the variance in this model was explained by the random factors ($R^2_{GLMM(m)}$ = 0.075, $R^2_{GLMM(c)}$ = 0.211, Appendix S2-F).

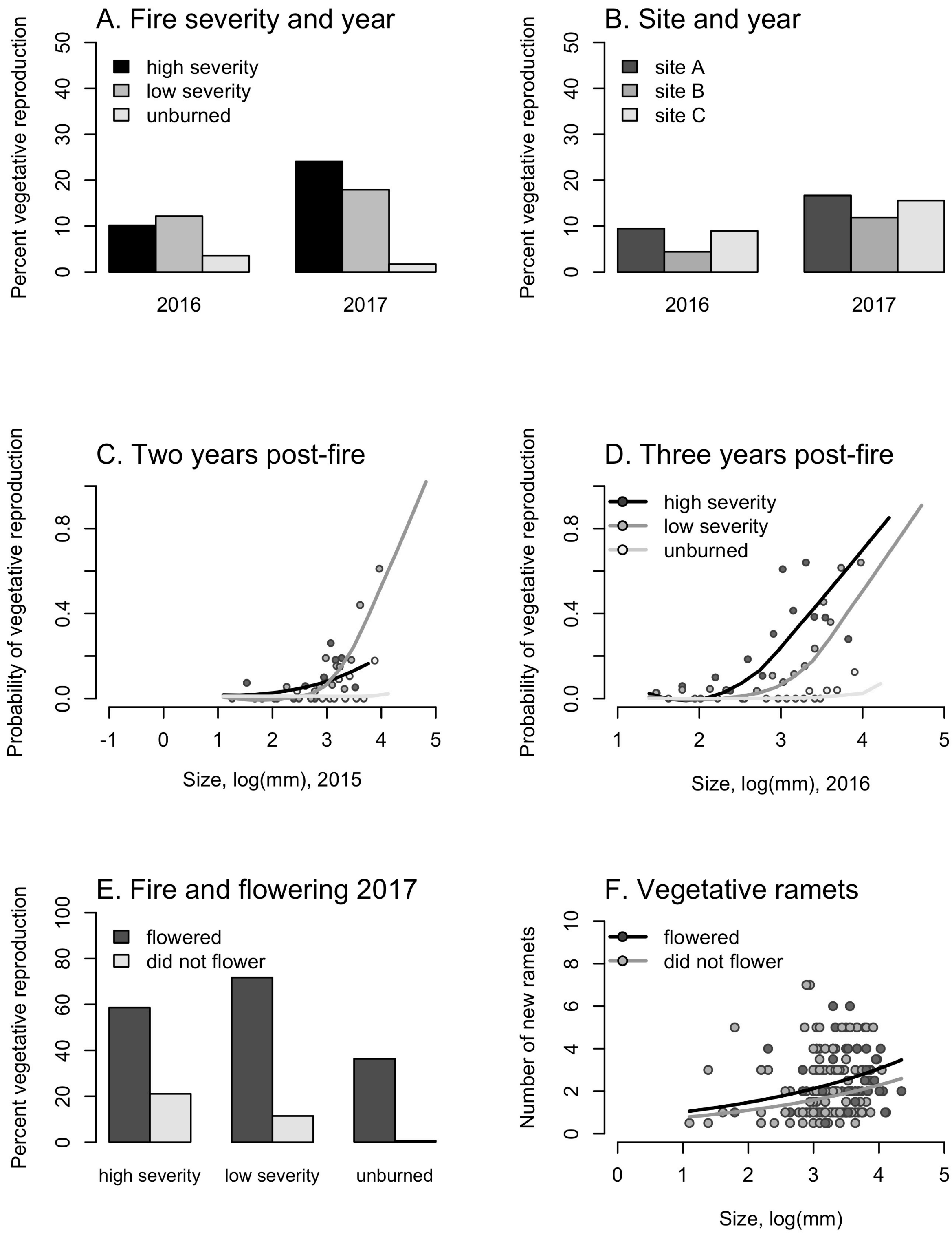

A. Fire severity and year
Percent vegetative reproduction
high severity
low severity
unburned
2016
2017
B. Site and year
Percent vegetative reproduction
site A
site B
site C
2016
2017
C. Two years post-fire
Probability of vegetative reproduction
Size, log(mm), 2015
D. Three years post-fire
Probability of vegetative reproduction
high severity
low severity
unburned
Size, log(mm), 2016
E. Fire and flowering 2017
Percent vegetative reproduction
flowered
did not flower
high severity
low severity
unburned
F. Vegetative ramets
Number of new ramets
flowered
did not flower
Size, log(mm)

Figure 3.5. Percent vegetative reproduction by fire severity and year (A), and by site and year (B). A and B include individuals at least 3 mm in 2016 and 4 mm basal diameter in 2017, the minimum sizes observed to vegetatively reproduce in each year. The relationship of fire severity to the probability of vegetative reproduction varied with individual size (C, D). Points and lines in these plots are average probabilities by fire severity class over a size interval that includes 10-39 individuals (see Methods section, Data analysis). The probability of vegetative reproduction also varied with flowering status and fire-severity class, and model predictions are shown here without leaf harvest (E). The number of new vegetative ramets produced per year increased with individual size and was greater if the individual had flowered (F). Points in (F) are individuals and lines are model predictions for individuals that flowered or did not flower.

Discussion

Fire severity, soil moisture, available light and non-timber forest product harvest are important drivers of plant population dynamics (Johnstone & Chapin 2006; Albrecht & McCarthy 2009; Gaoue & Ticktin 2010; Mandle *et al.* 2015a; Souza *et al.* 2018). Few studies, however, have disentangled their individual and interactive effects on plant populations (Ehrlén *et al.* 2016). Here I demonstrated that a key understory species responds to major management and abiotic drivers, and their interactions, at different points across its life cycle and in different ways with time since fire. For example, fire altered the relationship of early soil moisture to individual growth. Fire was associated with increased flowering probability one and two, but not three years post-fire, when available light became more important in describing flowering probability.

H1: Fire increased growth, flowering and vegetative reproduction

As predicted, fire increased beargrass growth and reproduction. Consistently higher individual growth in plots that experienced fire could be due to an increase in plant available soil nitrogen (Boerner 1982; Wan *et al.* 2001; Smithwick *et al.* 2005), reduced competition (Gillespie & Allen 2004; Shebitz *et al.* 2009b), and/or a specific adaptation to respond to tissue loss or fire by increasing allocation to growth (McNaughton 1983; Gowda & Raffaele 2004; Fang *et al.* 2008). Fire stimulated flowering, and high severity fire led to a higher probability of flowering compared to low severity fire one and two years post-fire. Other studies have also demonstrated that fire increases flowering (Hartnett 1990; Abrahamson 1999). However, the finding that fire led to increased flowering is in contrast to a beargrass study that found neither high nor low severity fire increased flowering (Shebitz *et al.* 2009b; Shebitz & James 2010). These authors suggest that fire stimulates flowering by increasing soil temperature (Maule 1959) and therefore the effect of fire on flowering is only observed (or is greater) at high elevation sites (like in this study), than at low elevation sites (as in their study). The relationship of soil temperature and flowering is worthy of further investigation. It is additionally possible that the effects of fire on flowering may only be apparent (or are more apparent) when the years following a fire correspond with mass flowering years, as they did in this study (Appendix 3.3-A).

Light is also known to be an important factor in beargrass flowering with some populations requiring 0.30 PAR (~50% canopy cover) to flower (Peter *et al.* 2017). I observed flowering in individuals experiencing between 13 and 70% canopy openness. While the light environment is clearly important to beargrass flowering, in my models, flowering was best described by fire severity class without canopy openness in 2015 and 2016, and by canopy openness without fire severity class in 2017. Mean canopy openness in high severity plots was 47.8%, followed by 40.3% in low severity plots and 21.5% in unburned plots (Appendix 3.4), and canopy openness did not change meaningfully over the course of the study. While I cannot fully tease apart the separate effects of canopy and fire, as canopy openness varied by fire severity class, results suggest that the non-canopy influences of fire on flowering, such as plant-available nitrogen, leaf removal or reduced competition, fade over time and that approximately three years post-fire, the light environment takes on increasing importance in the regulation of flowering. An experiment on the congener *Xerophyllum asphodeloides* found that fire and light (through canopy removal experiment) had additive effects on flowering (Bourg et al. 2015), Available light and fire may also independently promote flowering in *X. tenax*.

Beargrass has been called fire-adapted, in part because of its ability to re-sprout from rhizomes after fire (Shebitz *et al.* 2009b; Hummel *et al.* 2012). I found that the probability of vegetative reproduction was higher in burned plots compared to unburned plots both two and three years post-fire. Lowland studies of beargrass have found greater beargrass shoot numbers in areas that recently experienced fire (Shebitz *et al.* 2009b; Peter *et al.* 2017) and studies in other clonal plants have shown increased numbers of vegetative ramets after fire (Hartnett 1987; Anderson 1996; Menges & Root 2004).

Unlike the probability of vegetative reproduction, the number of new ramets per mother individual in this study was mostly related to individual size and did not vary with fire severity (Appendix 3.3-B). The fixed effects in the model of number of vegetative ramets had low explanatory power, meaning that additional unmeasured factors were likely driving this vital rate. These unmeasured factors might include soil temperature or litter depth, which are known to influence tiller production in grasses (Benson & Hartnett 2006), or other factors such as underground storage reserves (Hartnett 1987), or climatic factors over a longer time scale that have been shown to influence reproduction in a confamilial species (Iler & Inouye 2013).

Though I know of no other study that has assessed the relationship of beargrass flowering to vegetative reproduction, flowering (in the current or previous year) greatly increased the probability an individual would vegetatively reproduce in a given year, and the increase was proportionally highest for unburned plots, followed by low severity plots and lastly high severity plots. Vegetative reproduction in the absence of flowering was most common with higher fire severity (17% of individuals in high severity fire, 10% in low severity fire and 0.5% in unburned plots). Fire may have triggered vegetative reproduction independent of flowering through leaf damage or removal of competing vegetation (Shebitz & James 2010).

H1: Fire had varying effects on survival

As predicted, fire reduced survival in the first and second years after fire, and one-year post-fire, survival was reduced more with high severity than with low severity fire. Higher mortality in high severity burn plots was likely driven by the direct effects of fire. The high initial mortality of larger individuals one year post-fire could be an artifact of the inability to detect complete consumption of small individuals because I did not collect data or tag individuals before the fire occurred. Proportion seedling survival across sites in 2017 was higher in low severity than unburned plots, perhaps because soil moisture was higher in low severity plots (Appendix 3.4) (Plenzler & Michaels 2015; Pinto *et al.* 2016). Shebitz *et al.* (2009b) also found higher beargrass seedling survival rates two years post-fire in burned versus unburned plots. This could be due to greater seedling access to deeper organic and mineral soil in burned areas (Chappell & Agee 1996). Contrary to this finding, some studies have found decreased seedling survival in burned area post-fire due to increased water stress and herbivory (Campbell *et al.* 2016; Giljohann *et al.* 2017). In this study, high severity fire areas had the lowest soil moisture and almost no seedling recruitment (Appendix 3.3-C), and low severity fire areas had the highest soil moisture (Appendix 3.4).

H2: Fire mediated the relationship of soil moisture and growth

Contrary to expectation, increasing early season soil moisture resulted in greater growth in unburned and low-severity plots, but not in high-severity fire plots, perhaps because individuals in high-severity plots invested more in reproduction than growth (Villegas 2001). It is unlikely that growth in high-severity fire plots was limited by available nitrogen (Wagner & Fraterrigo 2015). Total nitrogen in beargrass leaves was higher in burned than unburned plots in this study two years post-fire (unpublished data), suggesting individuals in burned plots potentially had greater nitrogen resources available for growth than those in unburned plots.

H3: Leaf harvest did not influence growth or flowering, but did increase vegetative reproduction

Contrary to my expectations, and in in contrast with other studies (Ticktin *et al.* 2002; Martínez-Ramos *et al.* 2009; Mandle *et al.* 2015a), individual growth did not vary with leaf harvest. The reason may be that leaf harvest intensity in the study was low (Martínez-Ramos *et al.* 2009), and/or leaf harvest was only conducted once (Lopez-Toledo *et al.* 2012). A study on a palm species found that 66% leaf defoliation, but not 33 or 50%, led to a significant decrease in growth (Martínez-Ramos *et al.* 2009). The harvest intensity in this study was lower than 33%. At lower intensities of defoliation or folivory, plants may compensate for lost leaf tissue by increasing rates of photosynthesis or mobilizing stored reserves (McNaughton 1983; Oyama & Mendoza 1990; Anten *et al.* 2003; Gowda & Raffaele 2004; Fang *et al.* 2008; Muola & Stenberg 2018). Beargrass may be exhibiting compensatory growth that prevents us from detecting a negative effect of leaf harvest on growth.

Contrary to my hypotheses, leaf harvest did not influence flowering. Studies of other species have often shown that leaf harvest reduces flowering (Flores & Ashton 2000; Anten *et al.* 2003; Martínez-Ramos *et al.* 2009; Lopez-Toledo *et al.* 2012; Mandle *et al.* 2015a), or that harvest impacts on flowering depend on intensity (Mendoza *et al.* 1987; Oyama & Mendoza 1990). The removal of a large proportion of leaves may reduce a plant's ability to attain minimum levels of carbohydrate storage needed to achieve flowering (Weiner *et al.* 2009), but the harvest intensity in this study may have been low enough to avoid this effect. In one study of a tropical palm, 33% defoliation or greater reduced reproduction, but lower levels of defoliation increased reproduction (Mendoza *et al.* 1987). In another study of a perennial herb, 50% but not 10% or 25% leaf herbivory caused a reduction in sexual reproduction (Muola & Stenberg 2018). While these are different species, and herbivory is a different process than leaf harvest by humans, they provide evidence that harvest intensity matters. A study on a tropical tree whose branches are harvested revealed that that temporal variability in harvest intensity is also important in determining harvest impacts on tree populations (Gaoue, Horvitz & Ticktin 2011). Another possibility is that the method of avoiding removal of the leaves in the inner most whorl, or “heart” (one of several indigenous harvest practices), may have avoided potential negative impacts on flowering (or growth) (Ticktin 2004; Hummel *et al.* 2012; Hooper 2015). It is also possible that impacts of leaf harvest on flowering were not observable one year after harvest, if, for example, flowering is initiated more than one growing season prior. Leaf removal could influence reproductive allocation after flower bud or inflorescence formation (Delph 1990), but I were not able to test the effect of leaf harvest on the number of seed capsules produced.

Few studies have examined the impact of leaf harvest on asexual reproduction. Results of this study contrast with some studies where leaf harvest reduced (Flores & Ashton 2000), did not affect (Chazdon 1991; Mandle *et al.* 2015a), or inconsistently influenced (Schmidt *et al.* 2007) asexual reproduction. Though obviously different in many ways, insect leaf herbivory and grazing have been shown to increase allocation of resources to asexual reproduction (Jónsdóttir 1991; Shibel & Heard 2016). While leaf harvest increased vegetative reproduction in this study, more intense levels of beargrass leaf harvest, such as with commercial harvest, could have quite different consequences both because harvest techniques differ (sometimes including cutting with a knife or uprooting plants), and because more leaves are removed per individual (Thomas & Schumann 1993; Hummel *et al.* 2012).

H4: Responses to leaf harvest did not vary with fire severity

Contrary to this hypothesis, the effects of leaf harvest in this study did not depend on the presence of fire or on fire severity. Other studies have shown that the negative effects of leaf harvest on growth are reduced when they co-occur with fire (Mandle & Ticktin 2012). Results of this study suggest that the effects of leaf harvest and fire on beargrass are additive rather than interactive. Where leaf harvest and fire impacted beargrass demography, their effects were independent (fire severity and leaf harvest occurred in best models, but their interactions did not). This means that we can expect cultural leaf harvest to increase vegetative reproduction and to reduce survival in both burned or unburned areas. It also suggests that wildfire will influence beargrass populations similarly whether they have experienced leaf harvest for cultural use or not.

It is possible that assessing the effects of leaf harvest after more than one year, or after repeated defoliations (Martínez-Ramos *et al.* 2009) would provide different results.

No clear impact of fire season on beargrass demography

This study included beargrass populations across three sites. At sites A and C, wildfire occurred in July of 2014 (midsummer), while at site B wildfire occurred in September of 2014 (near the end of the growing season). As plots within sites were intended as a sample of the potential plots and sites that could have been measured (Eisenhart 1947; Bolker 2008), models that tested the relationship of management and abiotic factors to beargrass demography did so with site and plot incorporated as nested random effects (random intercept model). In most cases, site explained less than 5% of the variance in the overall model. Where site differences accounted for more than 5% of the variance in the overall model (flowering in 2015 and vegetative reproduction in 2017; see Appendix 3.2-G), there were not any clear differences between the two sites with July fire and the one site with September fire. Fire severity, rather than season (at least in comparing July to September fire) seems to be most important in determining impacts of fire on beargrass individuals, but a study with greater representation across the fire season, and a larger number of replicate locations would be necessary to test this assumption.

Conclusion

Fire increased beargrass growth and reproduction, had varying effects on survival, and mediated the relationship of soil moisture to beargrass growth. The relationship of flowering to vegetative reproduction also varied with fire severity. Light availability promoted flowering, though the effects of light could not be completely separated from fire severity. Leaf harvest increased the probability of vegetative reproduction and reduced survival. Leaf harvest effects did not vary with fire severity. High-severity fire increased reproduction more than low-severity fire, but also reduced survival more than low-severity fire. Low-severity fire also appears to provide the best conditions for seedling establishment, but manipulative experimentation is needed to test this observation.

The results of this study help disentangle the complexity of plant demographic responses to the effects and interactions of abiotic factors and management. Here, fire severity influenced and mediated the relationship of soil moisture and flowering to beargrass vital rates. I provide additional evidence that beargrass is fire-adapted by demonstrating that fire increases growth as well as both sexual and asexual reproduction. I also report beargrass flowering was always followed by vegetative reproduction in this study. Finally, low-severity fire is specifically known to promote leaf characteristics that are desired for Native American weaving practices (Rentz 2003; Hummel *et al.* 2012; Hummel & Lake 2015). This and other results suggest that fire and leaf harvest by Native Americans can increase the availability of beargrass leaves and flowers, two resources that provide important ecological and cultural ecosystem services.

CHAPTER 4. FIRE AND LEAF HARVEST SUPPORT THE LONG-TERM PERSISTENCE OF BEARGRASS POPULATIONS

Abstract

Though fire is a major disturbance in forested ecosystems, little is known about how contemporary changes to fire regimes are influencing understory plant population dynamics. Reducing wildfire risk has become a major goal of forest managers in the American West. Native American fire stewardship can reduce wildfire risk, suggesting collaboration across knowledge systems would improve forest management. To better understand impacts of changing fire regimes, and to explore the potential of collaborative approaches to forest management from an ecological perspective, I designed a demographic study of beargrass (*Xerophyllum tenax*). Beargrass is an understory lily-like herb that is traditionally managed through frequent low-severity fire as well as selective leaf harvest. I collected demographic and abiotic data over three years across nine populations and conducted a leaf harvest experiment to simulate Native American cultural use. These data were used to build integral projections models. With these models, I simulated stochastic population growth rates across future fire and leaf harvest scenarios. Finally, I analyzed the simulation results further using stochastic life table response experiments. I simulated three fire scenarios with scenario parameters based on available literature. Business as usual with regard to fire management was simulated with a 180-year fire return interval and 58% probability of high and 42% probability of low severity fire. Traditional fire stewardship or prescribed fire was simulated with fire every ten years and a 10% chance of high severity and a 90% chance of low severity fire. I also included a no fire scenario and simulated all three fire scenarios with and without leaf harvest. I found that no fire and business as usual with regard to fire management led to population decline (λ_s<1), while simulated traditional fire stewardship, led to rapid population growth (λ_s=1.28). Traditional stewardship supported beargrass persistence both because fire was more frequent and adult mortality was reduced. Traditional leaf harvest increased population growth rate in combination with traditional fire, but not in combination with the business as usual or no

fire regimes. Leaf harvest increased population growth rate primarily through vegetative reproduction. Both high and low severity fire, as well as leaf harvest, supported the long-term persistence of *X. tenax* populations. How *X. tenax* populations have persisted without fire remains an open question. Traditional stewardship supported population persistence, providing further impetus for collaboration across knowledge systems.

Introduction

Fire is major driver of plant composition and diversity in most forested ecosystems (Agee 1993; Vinton *et al.* 1993; Johnstone & Chapin 2006). Fire frequency and severity vary by forest type and are influenced by multiple factors including climate, as well as past fire suppression and exclusion (Dale *et al.* 2001; Heyerdahl, Brubaker & Agee 2001; Hantson *et al.* 2015; Steel *et al.* 2015; Walsh *et al.* 2015; Liebmann *et al.* 2016; Reilly *et al.* 2017). Past fire suppression and exclusion have led to forest densification and have increased fire severity, primarily in fuel-limited vegetation zones with relatively short fire return intervals (Perry *et al.* 2011; Steel *et al.* 2015; Spies *et al.* 2018). Increasing wildfire severity has also been reported in forest types with longer fire return intervals (Reilly *et al.* 2017). Further, in the continental and contiguous portion of the United States, Native American fire stewardship historically shaped forested ecosystem dynamics in many areas and provided ecosystem services (Pyne 1982; Boyd 1999; Stewart 2002; Anderson & Barbour 2003; Kitchen 2012; Walsh *et al.* 2018). This stewardship has been drastically reduced due to European colonization and its persistent impacts (Long & Lake 2018). As a result, even in vegetation zones where natural fire regimes have not been meaningfully altered by suppression and exclusion, cultural fire regimes have been effectively removed (Boyd 1999; Walsh *et al.* 2018).

Little is known about the impacts of changes to fire regimes on understory plants, which harbor the majority of plant biodiversity, support wildlife and provide other ecosystem services (Westerling *et al.* 2006; Gilliam 2007; Suchar & Crookston 2010; Abella & Springer 2015; Spies *et al.* 2018). The influence of fire on plant populations depends on the relationship of plant demography to fire characteristics, including fire frequency, severity and timing (Chappell & Agee 1996; Emery & Gross 2005; Souza *et al.* 2018). In some cases, lack of fire threatens the persistence of plants that have evolved responses to the direct or indirect effects of fire (Keeley & Zedler 1978; Caswell & Kaye 2001; Quintana-Ascencio *et al.* 2003; Souza *et al.* 2018). The absence of fire has also been linked to overall declines in understory diversity (Coop, Massatti & Schoettle 2010). Prescribed fire is often presented as a means to reverse this trend and to promote plant diversity, but greater understanding of the impacts of fire severity and frequency are needed, especially given that ecosystem responses to prescribed fire are often complex and site-specific (Cook & Halpern 2018).

Alternative fire management approaches to suppression and exclusion, including integration of traditional fire stewardship, are of increasing interest to government agencies as wildfire threat and financial costs of suppression increase (North *et al.* 2015; Lake *et al.* 2017, 2018; Thompson *et al.* 2018). Bridging of traditional ecological knowledge and western ecological knowledge may be particularly relevant in the challenging context of novel forest conditions created by fire suppression and climate change (Ryan, Knapp & Varner 2013). A major goal of forest management in many parts of the world today is reduction of wildfire risk. Importantly, the forest conditions that are the target of Native American fire stewardship overlap considerably with those that reduce wildfire risk (Hummel & Lake 2015). This suggest the value of collaborative and participatory approaches to management with tribes and other stewards (Charnley *et al.* 2014; Long, Lake & Lynn 2018). Designing projects focused on plants of cultural significance to tribes to explore the impacts of fire suppression would facilitate this bridging and collaboration (Lake 2013; Norgaard 2014).

For plants that are harvested for cultural or commercial purposes, fire and harvest represent layers of management simultaneously influencing plant demography and persistence (Sinha & Brault 2005). The effects of harvest on plant vital rates depend on multiple factors including co-occurring disturbances such as fire (Mandle, Ticktin & Zuidema 2015b) and climate change (Souther & Mcgraw 2014). Effects of harvest also vary with harvest intensity and variability, frequency, and plant life history, plant part harvested (Mendoza *et al.* 1987; Ticktin 2004; Gaoue *et al.* 2011; Lopez-Toledo *et al.* 2012).

Beargrass (*Xerophyllum tenax* (Pursh) Nutt. Melanthiaceae) is an iconic understory forest herb with cultural, ecological, economic and recreational value in the Pacific Northwest (Hummel *et al.* 2012; Hummel & Lake 2015). It is an ideal species to explore the impacts of fire, traditional stewardship, and leaf harvest as it is a fire-adapted, traditionally managed through frequent low-severity fire, and its leaves are harvested for cultural and commercial purposes (Shebitz *et al.* 2009b; Hummel *et al.* 2012; Lake & Long 2014). Its leaves are valued for basketry and regalia among Native American weavers across the Pacific Northwest (Hummel *et al.* 2012; Hummel & Lake 2015). Many weavers prefer leaf qualities promoted by recent low to moderate severity fire (Levy 2005; Shebitz 2005; Hummel *et al.* 2012). Beargrass is also a multi-million US dollar wild-harvested floral green (Schlosser & Blatner 1997), and is declining in some regions in both quantity and quality likely due to fire suppression and commercial harvest, including illegal harvest (Vance *et al.* 2004; Levy 2005; Shebitz 2005; Peter & Shebitz 2006; Shebitz *et al.* 2008; Dobkins *et al.* 2016).

To understand how beargrass populations respond to fire frequency, severity and leaf harvest, and in order to explore the potential impacts of reintroduction of traditional fire stewardship for beargrass in novel forest ecosystems, I utilized field data to parameterize integral projections models which were used to stochastically simulate different fire-harvest scenarios. Integral projection models (IPMs) allow incorporation of multiple environmentally-explicit drivers, covariates and interactions (Easterling, Ellner & Dixon 2000), and stochastic simulation with IPMs allow environmental conditions, such as disturbance and biophysical factors, to fluctuate over time (Davison *et al.* 2010; Ehrlén *et al.* 2016; Quintana-Ascencio *et al.* 2018). I built IPMs from regression models published elsewhere (see chapter three, this dissertation). I compare the no intervention scenario, or “business as usual” in terms of fire severity and frequency, with the reintroduction of traditional fire stewardship with fire every ten years, to a scenario with no fire. I simulate the fire scenarios with and without leaf harvest of beargrass for cultural use parameterized through a leaf harvest experiment. I use plant-level measurements of soil moisture and light as covariates in models to account for their effects and interactions with management factors.

Based on previous findings that fire increases beargrass growth and reproduction (see chapter three, this dissertation, Shebitz *et al.* 2009b), I hypothesized that “business as usual” or current fire return intervals of greater than 100 years would not allow for population persistence (stochastic population growth rate, λ_s<1), with or without leaf harvest, but that a fire return interval of 10 years would be sufficient to allow population persistence (λ_s>1). I further hypothesized that leaf harvest would increase population growth (λ_s >1) across fire scenarios given that it increased clonal reproduction (see chapter three, this dissertation).

Methods

Study species and area

Beargrass (*Xerophyllum tenax* Melanthiaceae) is an understory perennial herb. Beargrass is monocarpic, though the genet persists after flowering. Beargrass reproduces both sexually and asexually through tuber-like rhizomes (Vance *et al.* 2004; Hummel *et al.* 2012). In this study, flowering was always followed by vegetative reproduction (see chapter three, this dissertation). Beargrass is mostly self-incompatible with a racemose-paniculate inflorescence (Vance *et al.* 2004). Mass flowering occurs in irregular cycles that are poorly understood (Meyers *et al.* 2015). Leaves form a rosette similar in appearance to a grass and are tough and wiry. Beargrass occurs near sea level, as well as at higher elevations, with a range between 0-2200 m in the Pacific Northwest (Meyers *et al.* 2015). In the Pacific Silver Fir (*Abies amabilis*) zone forested locations where this study took place (Henderson 2009), plants were covered in snow in the winter and spring, and snowmelt occurred in April or May. Beargrass was the most abundant understory plant or was co-dominant with huckleberry (*Vaccinium* spp.).

Integral Projection Models

I collected demographic and abiotic data on >2,000 individuals in nine populations at three wildfire sites from 2015-2017 using a systematic random approach to identify populations in high severity, low severity and unburned areas and completed a leaf harvest experiment in 2016 (see chapter three, this dissertation). I pooled data across sites by fire severity and used this to build mixed-effects regression models of vital rates, including interactions. These models, along with seedling and new ramet size distributions, were used to build continuous size-dependent integral projection models with soil moisture, canopy openness, leaf harvest, and fire-severity class as covariates (Easterling *et al.* 2000; Ellner & Rees 2006) (Table 4.1). Seedling (< 3 mm basal diameter) survival was incorporated separately from non-seedlings as seedling survival is known to be impacted differently by factors such as soil moisture (Pinto *et al.* 2016). I tested for the presence of a seedbank by burying seeds and recording their germination after 1 and 2 years (Appendix 4.2). Given only 9% of non-germinated seeds were viable the next season, I did not include seedbank dynamics in these models. The IPM was developed as follows:

$$n(y, t+1) = \int_{\Omega} \kappa(y, x, \theta) n(x, t) dx \qquad \text{eqn 1}$$

Where the number of individuals, n, of size y in year $t + 1$ is equal to the kernel surface, $k(y, x, \theta)$ of all possible size transitions (i.e., survival, growth and fecundity) from size x at time t to size y at time $t + 1$, θ represents all covariates in the models, and $n(x, t)$ represents the vector of all sizes of individual plants at time t. The kernel can be further broken down into the survival-growth and fertility functions. The survival-growth function was constructed as:

$$p(y, \theta) = s(x, \theta)[1 - f_f]g(y, x, \theta), \qquad \text{eqn 2}$$

where $s(x, \theta)$ is the probability of survival, $\left[1 - f_f\right]$ is the probability of not flowering (because flowering is fatal), and $g(y, x, \theta)$ is the conditional size distribution with mean and variance calculated from the functions in Table 4.1 and bounded between 0.45 and 125 mm basal diameter. The fertility function was constructed as:

$$f(y,x,\theta) = s(x,\theta)f_f(x,\theta)f_n(x,\theta)p_g p_e(x,\theta)f_d(y)v_f(x,\theta)v_n(x,\theta)v_d(y), \qquad \text{eqn 3}$$

where $f(y,x,\theta)$ is the vector of size distribution of offspring in year $t+1$ resulting from reproduction in year t, $s(x,\theta)$ is the probability of surviving to year $t+1$, $f_f(x,\theta)$ is the probability of sexual reproduction, $f_n(x,\theta)$ is the number of seedlings produced per sexually reproducing individual, $p_g p_e(x,\theta)$ is the probability of germination and seedling establishment, and $f_d(y)$ is the size distribution of the seedlings. These equations are then multiplied by the same equations for vegetative reproduction, represented with the letter v, but without the germination and establishment processes. In the regression models, flowering was a predictor of vegetative reproduction and of the number of new vegetative ramets produced (Table 4.1). For the IPM, I used individual probability of flowering, $f_f(x,\theta)$, as the value for the flowering factor in those vegetative reproduction models.

After building these functions, I numerically integrated the kernels using the midpoint rule (Ellner & Rees 2006), generating nine 600 x 600 cell IPMs representing three fire severities (averaged across three sites) in each of three years. Covariates soil moisture, canopy openness, leaf harvest and flowering were set at their mean values by fire-severity class and year. I calculated the long-term asymptotic growth rate (λ) for each IPM using the popbio package in r (Stubben & Milligan 2007) (Appendix 4.1).

Table 4.1. Models and values incorporated into the Integral Projection Model. Best-supported models were chosen with AIC (see Chapter 3, Methods, Data Analysis).

Underlying IPM regression models and values	**Model main effects and interactions, or input values***	**Random effects structure**
Probability of survival (non-seedlings), binomial error, logit link	**Year 0-1:** fire-severity class, canopy openness x log size **Year 1-2:** fire-severity class, log size **Year 2-3:** fire-severity class x log size, leaf harvest x log size	Plot within site
Probability of survival (seedlings)	**Year 0-1:** high severity: 0.05 (estimate) low severity: 0.10 (estimate) unburned: 0.56 (observed mean proportion survival across all burn severities and all years, n=1167) **Year 1-2:** 0.56 (as above) **Year 2-3:** 0.56 (as above)	NA
Growth (non-seedlings), Gaussian error	**Year 0-1:** fire-severity class x log size **Year 1-2:** fire-severity class x log size **Year 2-3:** fire-severity class x early season soil moisture, early season soil moisture x log size	Plot within site
Growth variance	**Year 0-1:** 1.105*exp(2*-0.384 $\hat{y}$) **Year 1-2:** 1.105*exp(2*-0.384$\hat{y}$) **Year 2-3:** high severity: 0.6331*($\hat{y}$^-0.3416)*1 low severity: 0.6331*($\hat{y}$^-0.3416)*1.213 unburned: 0.6331*($\hat{y}$^-0.3416)*1.121	NA
Probability of sexual reproduction, binomial error, logit link	**Year 1:** fire-severity class, log size **Year 2:** fire-severity class, log size **Year 3:** canopy openness, log size	Plot within site
Number of seed capsules produced, linear model, Gaussian error	**All years:** -27.93 + 71.56*log size, Residual SE: 55.79 on 42 df; Adjusted R^2 = 0.206; F-statistic: 12.16 on 1 and 42 DF, p-value: 0.001156	NA
Seedlings per seed capsule	**All years:** observed proportions by fire-severity class high-severity fire area: 0.0014 low-severity fire area: 0.1713 unburned area: 0.2465	NA

Table 4.1. (Continued). Models and values incorporated into the Integral Projection Model. Best-supported models were chosen with AIC (see Chapter 3, Methods, Data Analysis).

Underlying IPM regression models and values	Model main effects and interactions, or input values*	Random effects structure
Size distribution of new seedlings	**All years:** mean = -0.052 (sd = 0.124) log mm, n=1168	NA
Probability of vegetative reproduction, binomial error, logit link	**Year 1:** fire-severity class, log size, flowering **Year 2:** fire-severity class, log size, flowering **Year 3:** fire severity class x flowering, flowering x size, leaf harvest	Plot within site
Number of new ramets vegetatively reproduced, Conway-Maxwell-Poisson error	**All years:** -0.637+ 0.366*log size + 0.291*flowering	Plot within site crossed with year
Size distribution of new vegetative ramets	**All years:** high-severity fire: mean = 1.745 (sd = 0.395) log mm, n=294 low-severity fire: mean = 1.726 (sd = 0.470) log mm, n=297 unburned: mean = 0.502 (sd = 0.798) log mm, n=40	NA

*Interactions imply inclusion of main effects within the interaction. 'Flowering' is a binary predictor (Y/N) and the flowering probability regression was used to set the value of 'flowering' for each individual in these equations. Size distributions and number of seed capsules are means (+/- standard deviation) and sample sizes. Due to low sample size, I ran a simple linear model for seed capsule production, only testing log size as a predictor and not including random effects. Due to lack of representation across levels of the random effects, I did not include seedlings in any models. Additional details of model specification can be found in Chapter 2, Methods, Data Analysis. The term "log size" refers to the basal diameter of individuals the previous year in log mm.

Fire and leaf harvest simulations

To compare the impacts of alternative future fire and leaf harvest regimes on beargrass long-term population persistence, I defined three fire regimes and simulated each with and without leaf harvest, for a total of six fire-harvest scenarios. To do this, I defined 12 possible environmental states for a Markov Chain that represented high severity, low severity and unburned IPMs one, two and three years post-fire. Given that a subset of plants across each fire severity were harvested two years post-fire, I also included a harvested and unharvested IPMs at three years post-fire by adjusting the coefficients of the harvest covariate in the underlying regressions, resulting in a total of 12 environmental states (Table 4.2). The stochastic sequence of environmental states for fire-harvest scenarios, BAU, or “business as usual”, and BAU-H or “business as usual with leaf harvest” was constructed using time-varying Markov Chain Monte Carlo Methods (Caswell 2001). Time-varying matrix transition probabilities were defined using the Weibull hazard function (Moritz *et al.* 2009). For the BAU and BAU-H scenarios, Weibull burn probabilities were set with a 180-year return interval (b=180), which is the mean fire return interval estimated in two studies for the Pacific Silver Fir zone in the Pacific Northwest (Agee, Finney & De Gouveruarn 1990; Morrison & Swanson 1990; Reilly *et al.* 2017). The shape parameter in the Weibull function, c, is a measure of the age or fuel-dependency of fire. A value of 1 indicates no fuel dependence. Larger values are positive dependence (fire probability increases with time given fuel increases) and values lower than 1 would indicate negative fuel dependence. I use a value of 1.5 to reflect some fuel dependency (Moritz 2003). The probability of high versus low severity fire was determined from proportions of low, moderate and high severity fire in the Pacific Silver Fir zone calculated from 1985-2010, spreading the probability of moderate severity fire evenly to high and low severity categories to get 58% chance of high severity fire and a 42% chance of low severity fire for BAU and BAU-H fire-harvest scenarios (Reilly *et al.* 2017, Table 7). For the BAU-H scenario (with leaf harvest), the environmental sequence three-years post-fire always included leaf harvest.

The second set of fire-harvest scenarios, PRCUF, “prescribed or cultural fire” and PRCUF-H, “prescribed or cultural fire with leaf harvest” was simulated with a fire occurring every 10 years. This is intended to represent re-introduction of Native American fire stewardship, as well as effects of prescribed burns. While much of the Native American knowledge of fire stewardship for beargrass has been lost, beargrass was and continues to be managed by Native Peoples through use of fire (O’Neale 1932;

Shebitz *et al.* 2009b; Turner *et al.* 2011a; Lake & Long 2014). Reported return intervals for cultural fire range from two to 20 years (Hummel *et al.* 2012). Given more information is available on burning for huckleberries (*Vaccinium* spp.) in the Cascades Range, and given huckleberry often co-occurs with beargrass (Anzinger 2002; Wray & Anderson 2003; Lepofsky 2009; Shebitz *et al.* 2009b), I also explored information on burning for huckleberry to help guide the tradition fire simulation for beargrass. Traditional burning is typically performed by cultural experts and the timing and frequency of fire depends upon the weather, the ecological context, and other factors (Lewis 1982; LeCompte-Mastenbrook 2015). For thinleaf/big/mountain/black huckleberry (*Vaccinium membraceum*) in the Pacific Northwest, a species that occurred with beargrass across all of the study sites, traditional fire frequency has been recorded to range from interannual to every 20 years (LeCompte-Mastenbrook 2015). I chose to model the effects of a 10 year return interval, the intermediate value of both estimates. For this scenario, the chance of low severity fire was set to 90% and high severity was set to 10% to reflect contemporary and historic documentation of Native American fire as often low severity (French 1999; Turner 1999; Beckwith 2004; Shebitz *et al.* 2009b). Low severity fire is also the most common target severity for prescribed fire in forests today (Ryan *et al.* 2013). For the leaf harvest scenario, PRCUF-H, the environmental sequence always included leaf harvest three years post-fire. This and all harvest scenarios include leaf harvest three years post-fire because that is the only year that I have leaf harvest data. Cultural leaf harvest has been reported most commonly one to three years post-fire (Hummel *et al.* 2012, p.27), though in Northern California it is generally the one year post-fire leaves that are gathered (F. K. Lake pers. comm.).

For the third set of fire-harvest scenarios, NF or “no fire” and NF-H or “no fire with leaf harvest”, for each year of the simulation, I selected unburned IPMs one, two and three years post-fire. For the NF-H, when the three-years post-fire IPM was selected, I always simulated leaf harvest. Given that mass flowering in 2015 resulting in flowering in one of the unburned plots with more available light, an event unlikely to occur every three years, I set the probability of selecting the 2015 IPM to 10%, spreading the remaining probability across the other two IPMs (45% chance each). The same probabilities were used for any unburned years in the first four fire-harvest scenarios (BAU, BAU-H, PRCUF, PRCUF-H).

For all models, years that burned were populated with the one year post-fire IPM for the selected fire severity, followed by the two and three years post-fire IPMs for the same fire severity. After three years, the sequence returned to the unburned IPMs. The sequence of environmental states was simulated with 50 replicates over 100 years, calculating the stochastic long-term population growth rate (λ_s) for each fire-harvest scenario as the mean over years over replicates and confidence intervals as λ_s +/- 1.96 *SE (the standard error over years over replicates) (Caswell 2001). Simulations were initiated with stable stage distribution of the unburned 2016 population. Adjusting this choice did not meaningfully alter the results. Removing the transient phase (first 20 years) had little impact on results and this stage was therefore retained for calculations.

Table 4.2. Environmental states (IPM kernels) used for simulation of stochastic long-term population growth rates across fire-harvest scenarios

Environmental state	Fire severity	Year of data collection	Years since fire	Cultural leaf harvest
1	high	2015-2016*	1	N
2	high	2015-2016	2	N
3	high	2016-2017	3	N
4	high	2016-2017	3	Y
5	low	2015-2016*	1	N
6	low	2015-2016	2	N
7	low	2016-2017	3	N
8	low	2016-2017	3	Y
9	unburned	2015-2016*	4+	N
10	unburned	2015-2016	4+	N
11	unburned	2016-2017	4+	N
12	unburned	2016-2017	4+	Y

*Data was not collected in 2014 (the year of the wildfires), so 2015 plant sizes were used in their place and mortality in 2015 was estimated based on charred plant remains. See chapter three, this dissertation for details.

Stochastic Life Table Response Experiments

To identify underlying causes of the difference in stochastic growth rate between the fire-harvest scenarios, I also conducted stochastic life table response experiments (SLTREs) (Caswell 2010). To do so, I first restructured the IPM kernels as 100 x 100 matrices, as computation was not feasible on the full 600 x 600 matrix. I first explored why low and high fire severity environments differed in stochastic growth rate, investigating effects of fire frequency, specific environmental states and specific matrix elements. I then analyzed effects of leaf harvest in the same way across the three fire regimes. Since the specific fire-harvest scenarios (BAU, PRCUF and NF) are constructed from the same 12 IPMs, varying in the frequency of occurrence of each

IPM, I did not have separate environments to compare complete fire-harvest scenarios with SLTRE.

The equation to calculate the environment-specific sensitivity, or the derivative of the stochastic growth rate with respect to the vital rate vector in environment i, from Caswell 2010, is as follows:

$$\left.\frac{d \log \lambda_s}{d\theta^{\top}}\right|_{u=i} = \lim_{T\to\infty} \frac{1}{T} \sum_{t=0}^{T-1} \frac{J_t\left[\boldsymbol{w}(t)^{\top} \otimes \boldsymbol{v}(t+1)^{\top}\right]}{R_t v^{\top}(t+1)\boldsymbol{w}(t+1)} \frac{d\, vec\, \boldsymbol{A}[\theta(t)]}{d\theta^{\top}} \qquad \text{eqn 4}$$

where J_t is the indicator variable that identifies if the environmental state i is present at time t, $\boldsymbol{w}(t)^{\top}$ is the transpose of the stochastic analogue of the deterministic dominant right eigenvector at time t, $\boldsymbol{v}(t+1)^{\top}$ is the transpose of the stochastic analogue of the deterministic dominant left eigenvector at time $t+1$, $\otimes$ is the Kronecker product, R_t is the growth of the total population from time t to time $t+1$, and $\frac{d\, vec\, \boldsymbol{A}[\theta(t)]}{dt}$ are the derivatives of the projection matrix $\boldsymbol{A}$ with respect to the lower-level parameters θ, and 'vec' is an operator that turns $\boldsymbol{A}$ into a vector (Caswell 2010). In order to identify the causes of differences in stochastic population growth rate across treatments (fire-harvest scenarios) that vary in both their environmental dynamics (fire and leaf harvest frequency) and vital rates, I calculated the effects of the stochastic sequence of environments in a simulation and the differences between treatments in vital rates across in each environment using the Kitagawa-Keyfitz decomposition method and applying equation 4. Analyses were run in R after translation from Matlab code provided by Caswell 2010.

Results

Integral projection models

Deterministic lambda values were consistently highest for low severity fire populations. In high severity fire populations, lambda increased with time-since-fire and exceeded unity only three years post-fire. Unburned populations had lambda values lower than the low severity fire populations. Unburned populations lambda values were lower than high severity populations only three years post-fire (Fig 4.1, Appendix 4.1).

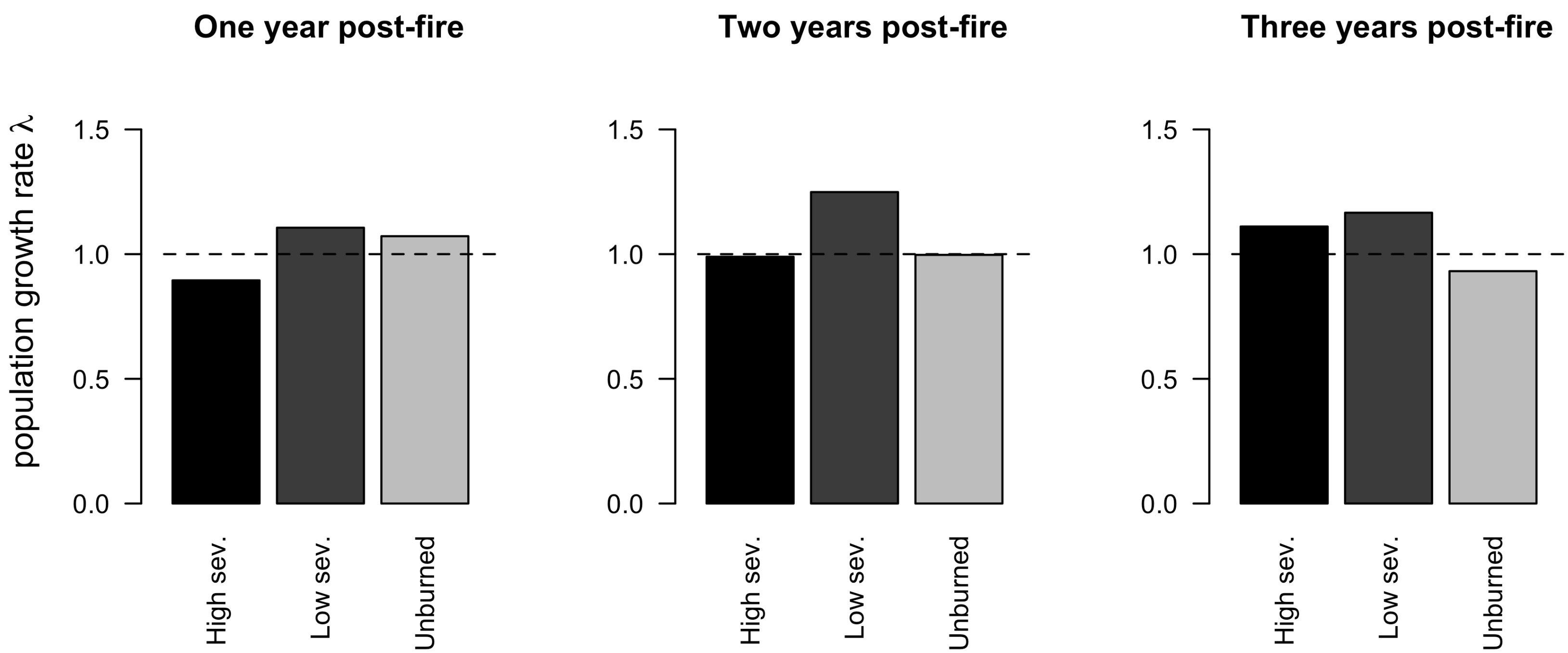


Figure 4.1. Deterministic long-term growth rates of populations across fire severities, one, two and three years post-fire.

Fire-harvest scenario simulations

The "business as usual" scenario, or simulation of a fire regime as has been observed in recent history, led to a population decrease of 0.93% per year (λ_s<1), representing population size declining from 100 to 51 over 100 years (Figs 4.2 and 4.3A). Prescribed or cultural fire every 10 years led to a stochastic population growth rate of 1.58% per year (λ_s>1), representing population size increasing from 100 to 637 over 100 years (Figs 4.2 and 4.3B). No fire was not significantly different from business as usual, leading to an average decline of 0.96% per year (λ_s<1), representing population size declining from 100 to 47 over 100 years (Figs 4.2 and 4.3C).

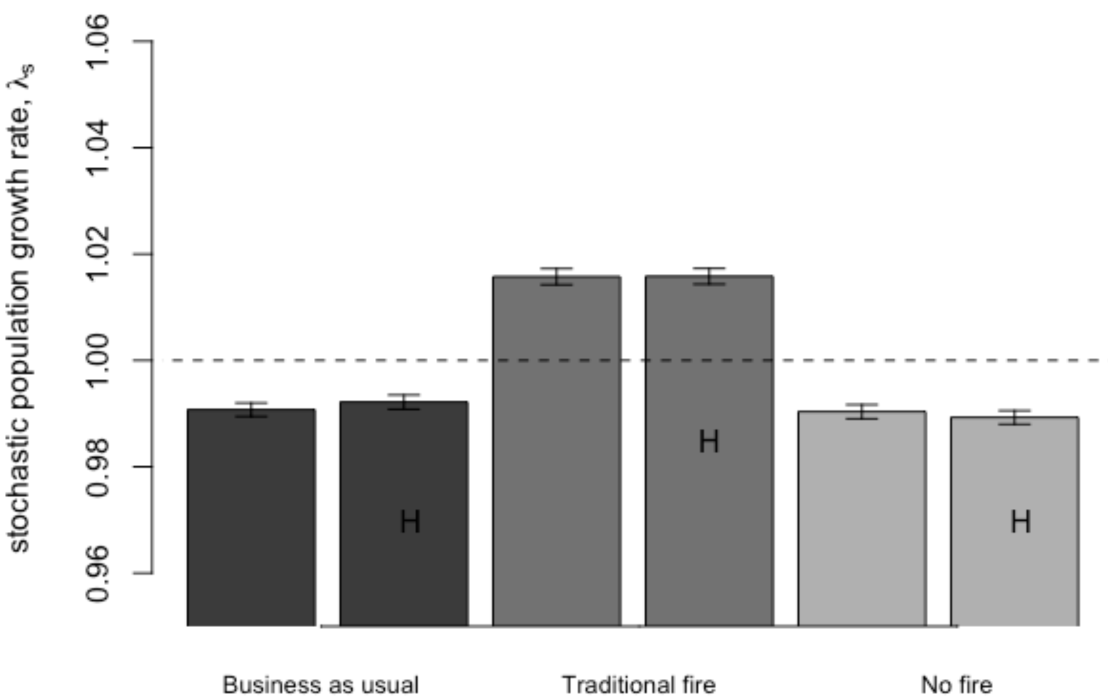


Figure 4.2. Long-term stochastic growth rate with 95% confidence intervals for fire-harvest scenarios. "H" on the bar represents scenarios with cultural leaf harvest. Fifty replicates over a 100-year simulation period with 600 by 600 cell IPMs.

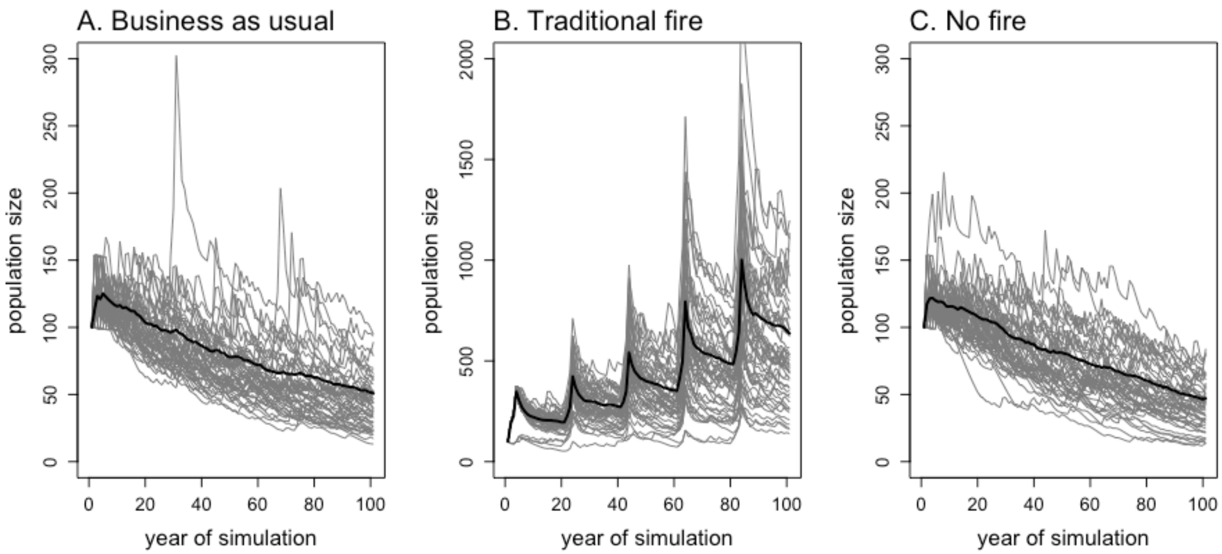


Figure 4.3. Changes in population size over the 100-year simulation period. Gray lines are the 50 replicates of the simulation. Black lines are the mean across replicates. Note that panel B has a different y-axis scale.

Simulated impacts of fire severity and frequency

Stochastic life table response experiments revealed that λ_s was higher in low severity fire populations across fire frequencies, that this difference increased with increasing fire frequency up to ~0.8 (80% chance of fire in any given year) and was due primarily to differences in the first year following fire (Fig 4.4A). Averaged across environments (years since fire), the difference between low and high severity populations in λ_s was primarily due to greater survival of large plants in low severity populations, as well as somewhat to greater seedling growth. Sexual reproduction contributed in the opposite way to the difference in λ_s between low and high severity areas: seedling production contributed to higher λ_s in high severity than low severity fire areas (Fig 4.4B).

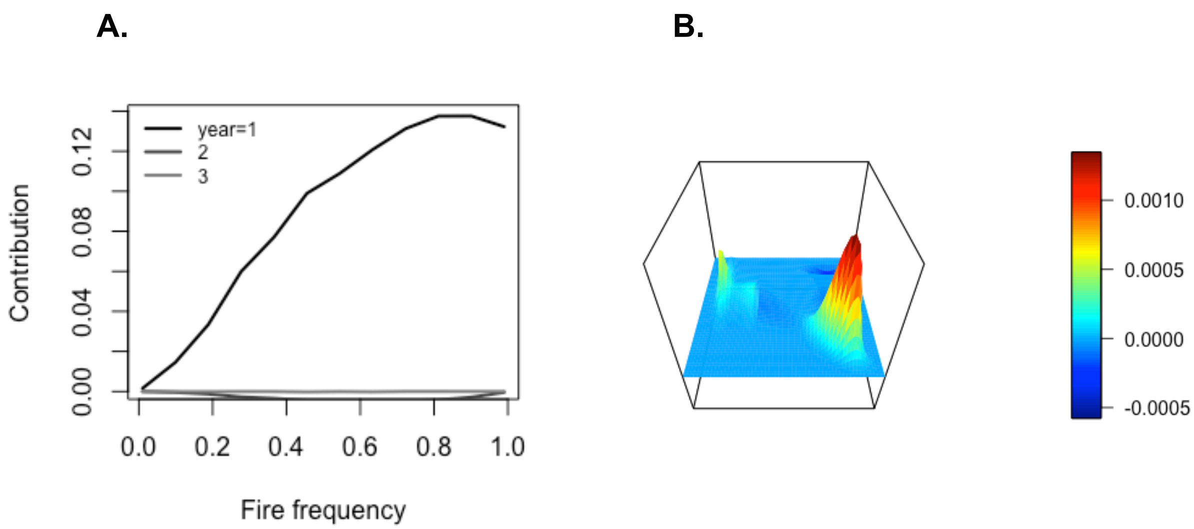


Figure 4.4. Contributions of the one, two and three years post-fire environments to the stochastic growth rate difference between low and high severity fire populations (**A**). Simulated over 100 years. **B.** Relative contribution of transitions across a 60 x 60 matrix to differences in stochastic growth rate between low and high severity fire populations with fire frequency set to 0.54. Increasing fire frequency increased the relative importance of survival of large individuals. Upper left corner is matrix element [1,1].

Simulated impacts of leaf harvest for cultural purposes

Leaf harvest for cultural purposes did not significantly influence long-term stochastic population growth rates in any fire scenario (overlapping confidence intervals) (Appendix 4.3).

Discussion

As I hypothesized, business as usual with regard to fire management may not allow long-term persistence of beargrass populations in the absence of other disturbances. This is true despite the fact that unburned environments in the simulations included some flowering, seedling recruitment and clonal reproduction. Also, as predicted, traditional fire management, of higher frequency and lower severity, was more than sufficient for population persistence. This type of management also supports access to leaves of the appropriate quality for weaving (Hummel & Lake 2015). Though I expected a positive effect across all fire scenarios, cultural leaf harvest did not significantly impact stochastic population growth rate. Lack of fire, and particularly low severity fire, could threaten beargrass population persistence, though other disturbances not evaluated here (e.g., snow avalanches, windfall gaps, timber harvest, lahars; Hemstrom & Franklin 1982; Teensma 1988) can perhaps maintain beargrass populations in the absence of fire.

Influence of fire severity on population dynamics

Fire severity, defined by tree mortality as well as the degree of scorch or consumption of beargrass plants (see chapter three, this dissertation), influenced population dynamics primarily through the mortality of large plants in high severity fire in the year following fire. The large contribution of survival to beargrass λ_s would be expected given it is a long-lived iteroparous perennial (Franco *et al.* 2004). The sensitivity of beargrass populations to adult survival suggests the importance of fire and fuels management, and well as timber and leaf harvest techniques that are careful to avoid beargrass mortality. It should be noted, however, that the importance of adult mortality may be overestimated. Because I did not collect data the year the wildfires occurred (2014), the measurements of adult mortality one year post-fire were based on charred remains. This could have led to an underestimate of mortality, particularly mortality of small plants.

In addition to demographic considerations, fire severity is also important in terms of its effects on leaf characteristics related to weaving. Many weavers, particularly at the southern end of beargrass' range, prefer beargrass leaves from areas recently burned with a low to moderate severity fire (Hummel *et al.* 2012). Burned leaves tend to be longer, thinner and more pliable (Rentz 2003), which is preferred for most weaving techniques. Partial shade, which is more likely to occur after a low severity fire, is also associated with leaves that are pliable for a longer period of time (Hummel *et al.* 2012). Reintroduction of low severity fire would therefore support the needs of weavers who use beargrass.

Influence of fire frequency on population dynamics

Similar to other fire-sensitive plants, fire frequency made the difference between beargrass persisting or perishing in the simulations (Caswell & Kaye 2001; Kaye *et al.* 2001; Quintana-Ascencio *et al.* 2003; Menges & Quintana-Ascencio 2004; Souza *et al.* 2018). A long fire return interval, specifically in this study a fire return interval of more than ~30 years with high severity fire or more than ~90 years with low severity fire caused population decline (Appendix 4.4). However, the frequency of fire necessary for plant persistence depends on the environmental context (Quintana-Ascencio *et al.* 2018). Beargrass occurs across a range of environments including a large elevational range, different soil types and different vegetation zones with different productivities (Hummel *et al.* 2012). Beargrass may require different disturbance frequencies to be maintained in different areas depending on these and other factors.

The fire frequency required to support beargrass populations at the sites in this study (30-90 years) is lower than that estimated from fire history studies for the Pacific Silver Fir Zone where these sites are located, which begs the question of how plants are persisting at these sites. This question has been explored by other researchers (Peter *et al.* 2017). One possibility is that beargrass populations in environmental contexts like the one in this study are maintained by other disturbances such as windthrow canopy gaps, road cuts or timber harvest. While logging may stimulate beargrass by increasing available light, most sources have found logging (skidder/dozer ground logging) harmful to beargrass. Authors cite soil compaction, damage to rhizomes or competition with other herbs to explain the limited recovery of beargrass 20 years or more after logging (Hummel *et al.* 2012). Timber operations that remove only a portion of trees and which are mindful to avoid direct and indirect damage to plants may sustain populations, but it is unlikely that this type of management occurred at the study sites. Study sites are located along logging roads, and the timber stands where plots were located were either never logged or logged over 80 years ago (Phil Monsanto, USFS Mount Hood Clackamas Ranger District, unpublished data).

Another possibility is that natural and/or anthropogenic fire return intervals were higher at the study sites than estimated in the two studies used to generate the fire return interval for the simulations (Agee *et al.* 1990; Morrison & Swanson 1990). Study sites were at a higher elevation than the average elevation of these studies, and have a south and eastern aspect, two factors known to increase fire frequency (Hemstrom & Franklin 1982; Teensma 1988; Morrison & Swanson 1990). It is also possible, given that fire suppression was instated between 1910 and 1950 (Morris 1934), and that beargrass is long-lived (estimated at least 60 years, Peter 2017), populations could be on a slow decline in some areas (Peter & Shebitz 2006).

Climate change is also expected to influence fire severity and frequency. In the Pacific Northwest, the majority of precipitation falls in the winter and spring, with very dry summers (Parson *et al.* 2003). Climate models predict greater spring and lesser summer and autumn precipitation over the next century (Mote & Salathe Jr 2010). Lower summer and autumn precipitation, combined with higher temperatures, is projected to increase the growing season potential evapotranspiration (Abatzoglou, Rupp & Mote 2014). These projections, along with a lengthening fire season, also portend greater wildfire risk (Dale *et al.* 2001; Westerling *et al.* 2006). The simulations suggest that more frequent fire, even high severity wildfire, would benefit beargrass populations in the mid to high elevation Pacific Silver Fir Zone.

Cultural leaf harvest has no detectable effect on population growth

Leaf harvest for cultural use did not significantly influence long-term beargrass population growth rate, suggesting that Native American gathering practices are sustainable for plant populations. The low-intensity cultural leaf harvest examined here (removal of 10 leaves per plant from the inner leaf whorl of the plant) is an approximation of one of several indigenous leaf harvest techniques (Hummel *et al.* 2012; Baldy 2013; Hooper 2015). In some areas, harvest of the outer leaves is preferred to the inner leaves, which may or may influence population growth rate differently (Hummel & Lake 2015). Commercial harvest of beargrass typically involves higher plant-level and population-level harvest intensity (Thomas & Schumann 1993;

Hummel *et al.* 2012). Weavers report that commercial harvest is reducing access to beargrass (Shebitz 2005). More intense harvest could reverse the observed reproductive benefits of harvest (Mendoza *et al.* 1987; Ticktin & Johns 2002; Endress *et al.* 2004; Martínez-Ramos *et al.* 2009; Souza *et al.* 2018), but demographic impacts of more intense harvest on beargrass have not been experimentally studied.

Conclusion

Here I implemented stochastic integral projection model simulations to examine the impact of fire frequency and severity, leaf harvest and abiotic factors on the persistence of a culturally and ecologically important understory herb. The results suggest that Native American fire stewardship allows for population persistence of beargrass and that non-intervention, in the absence of other disturbances, does not. I also demonstrate that cultural leaf harvest of beargrass, one Native American traditional leaf harvest technique, is compatible with beargrass population persistence. Using stochastic life table response experiments, I show that low severity fire leads to higher stochastic population growth rate than does high severity fire due to greater survival of large plants one year post-fire. Moving towards the implementation of management solutions, the value shown here of traditional knowledge to ecosystem recovery highlights the importance of collaboration with tribal resource management departments for the maintenance of ecological and cultural values derived from public lands. Overall, the fire and leaf harvest simulations suggest that lack of fire is potentially a concern for beargrass population persistence, and this could be true for other understory species in the Pacific Northwest.

CHAPTER 5. THE INTEGRATION OF ETHNOGRAPHIC AND ECOLOGICAL FINDINGS AND THEIR IMPLICATIONS FOR SOCIAL-ECOLOGICAL SYSTEMS THEORY AND FOR BEARGRASS MANAGEMENT

Overall findings

The main findings of this dissertation are that beargrass is deeply important to many tribal communities (Chapter 2), that access is a major challenge for some weavers (Chapter 2), and that beargrass plants benefit from both periodic fire and low-intensity leaf harvest (Chapters 3 and 4). Resilience in this social-ecological system from a social-cultural perspective is likely driven by the deep spiritual importance of beargrass, its irreplaceability, the cultural values of respect and reciprocity embedded in beargrass traditions, and the ability to innovate alternative management practices in the absence of fire. In the ecological study, fire increased growth, sexual and vegetative reproduction, reducing survival only in the first year after fire. Leaf harvest that simulated gathering for cultural use reduced plant survival while increasing vegetative reproduction. Fire interacted with soil moisture and flowering, but not harvest, to influence *X. tenax* vital rates. *Xerophyllum tenax* demography is affected by the interaction of abiotic and management factors. These factors and interactions all need to be considered in maintaining cultural and ecological ecosystem services derived from beargrass populations. Examples of these services include pollen rewards for insects, early spring forage for deer and elk, and leaves for the perpetuation of basketry traditions among Native Americans. Scaling up impacts from the individual plant to the beargrass population level, my simulations of future scenarios suggested that the lack of fire as well as business as usual with regard to fire management are associated with population decline, while simulated traditional fire stewardship, led to population growth. Traditional stewardship supported beargrass persistence both because fire was more frequent and also because adult mortality was reduced with lower severity fire. Traditional leaf harvest did not significantly influence population growth rate in simulations. Both high and low severity fire increased the long-term stochastic growth rate of *X. tenax* populations. Traditional stewardship supported population persistence, providing further impetus for collaboration across knowledge systems.

Strengthening biocultural traditions

Steps that can be taken to strengthen this biocultural system are discussed in my previous chapters, and include broader recognition of tribal sovereignty, improved access for cultural practitioners to beargrass gathering sites, and increased application of low-severity fire. Broader recognition of sovereignty includes education of the public on this topic, as well as specific education and training for natural resource managers that includes tribal sovereignty and tribal history. Improving access includes helping cultural practitioners and those interested in learning beargrass traditions to overcome barriers, including economic barriers, to learning opportunities. Increasing the acreage of prescribed low-severity fire was also recommended, though is not simple to implement. People or programs that conduct burns must address issues such as liability, access to land, financial and personnel resources, and the risks and challenges associated with the altered ecological context of contemporary forests due to timber harvest, fire suppression, climate change and other factors. Increasing application of low-severity fire in a way that benefits beargrass weavers is probably best achieved through collaborations between cultural practitioners and land managers. These collaborations can be challenging territory; achieving desired ecological outcomes is intimately tied to strategies to overcome the trust barrier and to build relationship and understanding across differences. Training, incentives and/or benefits for people who choose to take on this important and challenging work are needed to encourage further bridging.

Reconciling western and indigenous science

Based on my experience in this project, I would say that Indigenous science and academic ecological science are less in conflict over beargrass management, than they are focused on different goals. Cultural values derived from meaningful access, relationship with, and gathering of understory plants are generally a minor concern in the ecological literature, while these would be of major importance to Indigenous resource management systems. Fortunately, at this point in history, both knowledge systems in the Pacific Northwest of the U.S. generally look favorably upon use of low-severity prescribed fire, though the specific reasons for favoring this management tool may differ. A key difference between knowledge systems may be that Indigenous stewardship places more emphasis on practices that demonstrate humility, gratitude for, and reciprocity with other living beings, while academic science is mostly separated from overt spiritual practices such as prayer, offerings and listening to plants. The idea that all living things have a place and a value in the world seems to be a shared value. Apart from these general statements, it is difficult for me to compare academic ecological science and Indigenous science in regard to beargrass because I was not able to comprehensively represent the range of Indigenous knowledge and wisdom in connection to beargrass, because much knowledge and connection to tradition has been lost through persecution of Indigenous Peoples, and because these two ways of knowing are typically represented in a hybridized way by indigenous scientists and cultural practitioners. Indigenous knowledge evolves with recent observations and experimentation, and academic ecological findings are not excluded from consideration in this evolution. For example, modeling of snowpack was mentioned as a source of information used in the decision to move tribal land management efforts to new areas.

Study limitations

As with any study, there are sources of uncertainty that should caution the reader in the interpretation of findings. While this project was longer than the average plant demographic study, the relatively short duration of the field work (three years), the focus on mountainous habitat, the small number of cultural practitioners interviewed, and some assumptions that had to be made in building the simulations, all have implications for how the results should be interpreted. A longer field study could have increased the sample size, especially of flowering plants, increasing the statistical power to detect drivers of reproduction, and providing the opportunity to detect longer-term effects of management. The response of beargrass populations in the Cascades Mountains in this study may not translate to lowland areas or other mountain ranges where climatic, edaphic, disturbance and other site characteristics vary. Working with and interviewing a larger number of weavers could provide stronger support for specific conclusions and reveal diversity in knowledge and practice at multiple scales that could not be captured in this study. In the simulations of future beargrass population size under different management scenarios, I had to make some assumptions about processes I did not directly observe, or for which sample size was limited. These included the mortality rate of seedlings and adults in the year of a wildfire, and the survival and growth rates of seedlings in high-severity fire plots because less than three seedlings were observed to recruit in areas of high severity. I was, however, able to investigate the sensitivity of simulations to these unobserved parameters by running simulations across a range of potential values. The simulations in this study also assign seedlings the same vital rates as small clonal ramets. Finally, simulations exclude the impacts of seed and seedling herbivory, which is discussed in more depth below.

Opportunities for future study

From an ecological perspective, there are several aspects of the ecosystem that I would consider interesting and important for future work. One of these is the influence of herbivory on beargrass demography. In this study, flowering stalks were commonly broken off and missing (I hypothesized this was deer herbivory), seeds were harvested by chipmunks (likely *Neotamias townsendii*, pers. observ.), and beargrass seedlings may have been eaten by the western pocket gopher (*Thomomys mazama*), an herbivore who was living close to where seedlings recruited. Herbivory of leaves and fruits could have strong impacts on population structure and dynamics and would be fascinating to incorporate into future models. Mass flowering is another interesting aspect of beargrass demography. I observed mass flowering in different regions of the forest in different years. The controls on mass flowering in beargrass are not known. A long-term study over a broad geographic region that included individual-level demographic measures as well as climatic data would help to build an understanding of biotic and abiotic controls on mass flowering. It may also be interesting to consider periodicity of flowering in combination with periodicity of management, including use of fire by Native Peoples. Finally, the belowground aspects of beargrass demography and ecology are not well known. I would be interested to investigate how long ramets stay connected to each other, at what distance from a mother individual vegetative ramets are produced and how this varies across ecosystems. Mycorrhizal components of beargrass demography, and the size of underground plant parts may also be important as drivers of beargrass demography. Finally, given the disjoint distribution of beargrass in the Pacific Northwest, it may be interesting to investigate the genetic relationship of lowland/highland as well as Cascade Mountains/Rocky Mountains populations of beargrass.

Leaf harvest is a key part of indigenous management for beargrass and harvest of plants and plant parts is also central to Indigenous resource management systems more generally. I found the sensitivity of beargrass plants in this study to low-intensity leaf harvest intriguing. The harvest technique tested in the field in this study increased plant population growth rates in simulation through an increase in vegetative reproduction. While the idea that non-lethal harvest can increase growth or reproduction might be familiar for farmers or gardeners who prune their plants, plant responses to human harvest in the wild aren't broadly discussed in the ecological literature. Specific harvest techniques for beargrass, which vary regionally and by weaving style, may also have different impacts. I would predict that removing outer leaves (coiled weaving style) would have less impact on beargrass demography than removing newer inner leaves (twined style) because removal of inner leaves may more closely mimic animal herbivory, and therefore plants may be more likely to have evolved responses to this type of tissue loss. Simulating more intense levels of harvest could also be informative for understanding commercial harvest impacts. Findings here suggest that commercial harvest, even harvest that follows the protocols set by land management agencies such as only gathering by hand and not uprooting plants, could have a strong influence on beargrass demography and plant population growth, though this was not explicitly examined in this project. Regardless of the plant population impacts of commercial harvest, in order to improve access for weavers to quality leaves, competition between commercial harvesters and cultural gatherers needs to be reduced. Turning over tracts of public lands to the sovereign control of tribes could help in this effort.

From resilient to thriving social-ecological systems

From the perspective of social-ecological systems, beargrass populations and the indigenous cultural practices associated with them have been resilient to changing conditions. The plants themselves are resilient to fire and to leaf harvest, with the ability to resprout and increase growth or reproduction after these disturbances. They are also flexible in that they may reproduce vegetatively or sexually, however sexual reproduction does not appear to occur without subsequent vegetative reproduction. From a social perspective, cultural practitioners have invested in solutions and innovations to overcome external challenges and impediments to perpetuation of cultural practice, such as pruning or burning individual plants when they can't broadcast burn, or potentially processing unburned leaves more intensively to get similar leaf quality to that found in burned areas. While beargrass plant populations and associated cultural practices have been resilient, resilience alone does not imply a thriving or healthy system. Weaving traditions were described by one weaver as "reawakening" in her community. In another community, weaving with beargrass was described by a weaver as a "dying art." Beyond resilience, it is essential to consider how we can move this and similar systems towards increasingly healthy, vibrant, thriving states. I think this requires maintaining positivity and hopefulness for future generations in the wake of global change. It is increasingly clear that progress is a group effort that requires the work of people with many different backgrounds. For those doing this type of work, change and reconciliation involve stepping outside our comfort zones and questioning our own assumptions and those of our disciplines and upbringings. Indigenous Peoples have been here for millennia and have been through past climate change as well as European colonization. The broader public has a lot to learn from Indigenous Peoples, and we all have many reasons to feel optimistic about a brighter future.

APPENDICES

Appendix 2.1. Semi-structured interview questionnaire

Title: Integrating ecological and educational approaches in the biocultural conservation of beargrass (*Xerophyllum tenax* Melanthiaceae)
Georgia Hart-Fredeluces, M.S.
Department of Botany
Project dates: May 1st 2016- March 31st 2019

Questions for semi-structured interviews on basketry, beargrass and fire

Name:
Employment:
Work related to Natural Resources or weaving:
Age:
Gender identity:
Tribal Affiliation:
Ethnicities:

1. Tell me about your relationship with basketry.
2. Tell me about your relationship with beargrass.
3. How abundant and accessible is beargrass for you, your family, and your community?
4. Has beargrass abundance or accessibility changed over time? If so, how has it changed and what seems to be the reason for these changes?
5. Is there a proper way to gather beargrass? If so, what is the proper way to gather beargrass?
6. Who gathers beargrass?
7. Do you gather beargrass for others? Who and Why?

8. How many leaves would you need for each type of basket? How many plants might this represent?
9. What else, besides gathering leaves, might occur while at a gathering site and at this site throughout the year?
10. What is the proper way to care for and manage beargrass and beargrass gathering sites?
11. What kind of leaves, or which leaf characteristics are most desired for use for each type of basketry?
12. What are some undesirable leaf characteristics?
13. What can be done to promote leaves of the best quality?
13. How do harvest, fire and shade influence the quality or abundance of the plants?
14. How has the relationship of your community to fire changed over the course of your lifetime and even through past generations?
15. How has climate change [including changes to temperature and precipitation] impacted this plant? How do you think climate change may impact the plant or access to the plant in the future?
16. When do plants flower and under what conditions? How does flowering relate to harvest, fire and other site conditions?
17. How might scientific research support or not support tribal needs with respect to beargrass or other wild-gathered plants?
18. How could government agencies or private land owners best support weavers?
19. What have you noticed about Native youth interest in basketry involving beargrass? How has interest changed over time?
20. How do you pass knowledge about beargrass care, management and uses to younger generations?
21. What are the most important things to be taught by mentors that should be learned by students in locating, harvesting, processing, and using beargrass?
22. How could formal school curriculum best support tribal needs for education of Native youth with concern to significant plants?
23. What are the values of basketry traditions? What are the values of basketry traditions that incorporate beargrass?

24. What are your recommendations for strengthening cultural traditions related to beargrass?

Appendix 2.2. Institutional Review Board research approval

Office of Research Compliance
Human Studies Program

UNIVERSITY of HAWAI'I®
MĀNOA

MEMORANDUM

March 10, 2016

TO: Georgia Hart
Principal Investigator
Botany Department

FROM: Denise A. Lin-DeShetler, MPH, MA
Director

SUBJECT: CHS #23766- "Integrating Ecological and Educational Approaches for the Biocultural Conservation of Beargrass (Xerophyllum temax Melantiaceae)"

Under an expedited review procedure, the research project identified above was approved for one year on March 9, 2016 by the University of Hawaii (UH) Human Studies Program. The application qualified for expedited review under CFR 46.110 and 21 CFR 56.110, Category (7).

This memorandum is your record of the Human Studies Program approval of this study. Please maintain it with your study records.

The Human Studies Program approval for this project will expire on March 8, 2017. If you expect your project to continue beyond this date, you must submit an application for renewal of this Human Studies Program approval. The Human Studies Program approval must be maintained for the entire term of your project.

If, during the course of your project, you intend to make changes to this study, you must obtain approval from the Human Studies Program prior to implementing any changes. If an Unanticipated Problem occurs during the course of the study, you must notify the Human Studies Program within 24 hours of knowledge of the problem. A formal report must be submitted to the Human Studies Program within 10 days. The definition of "Unanticipated Problem" may be found at: http://hawaii.edu/irb/download/documents/SOPP_101_UP_Reporting.pdf, and the report form may be downloaded here: http://hawaii.edu/irb/download/forms/App_UP_Report.doc.

You are required to maintain complete records pertaining to the use of humans as participants in your research. This includes all information or materials conveyed to and received from participants as well as signed consent forms, data, analyses, and results. These records must be maintained for at least three years following project completion or termination, and they are subject to inspection and review by the Human Studies Program and other authorized agencies.

1960 East-West Road
Biomedical Sciences Building B104
Honolulu, Hawai'i 96822
Telephone: (808) 956-5007
Fax: (808) 956-8683

Please notify this office when your project is complete. Upon notification, we will close our files pertaining to your project. Reactivation of the Human Studies Program approval will require a new Human Studies Program application.

Please contact this office if you have any questions or require assistance. We appreciate your cooperation, and wish you success with your research.

Appendix 2.3. Interview transcripts

Transcript 1:

Name: Sara Siestreem
Formal and/or informal positions and titles: Artist and Educator
Age: 42
Gender identity: Female
Tribal Affiliation: Hanis Coos
Ethnicities: Native American and Hispanic

14. Tell me about your relationship with basketry.

    I studied weaving with the Grand Ronde. My teachers are Greg Archuleta (Grand Ronde) and Greg A. Robinson (Chinook Nation). I am a weaver. I created and run a weaving program for the Coos, Lower Umpqua, and Siuslaw People. Our weaving tradition has been hibernating since the 1850's. We are working as a community to awaken it.

15. **Tell me about your relationship with beargrass.**

    Bear Grass is a significant weaving material to the Coos, Lower Umpqua, and Siuslaw people. When it is present on a basket it indicates the basket is used for ceremonial purposes. We use overlay technique to weave it into our baskets, it is only visible on the outside of the basket. Its presence in our historic baskets is also significant from an ancient gardening perspective. Typically, in this region Bear Grass is found in mountainous elevation. Our traditional homeland is at sea level. We have located extensive Bear Grass beds in close proximity to our traditional village sights. Also, in and around these beds are as many as 45 other food, medicine, and cultural use plants. This phenomenon indicates a cultivation that would have taken many generations to establish.

16. How abundant and accessible is beargrass for you, your family, and your community?

    It is both abundant and accessible.

17. **<u>How has its abundance or accessibility has changed over time and why?</u>**

    We are too new to this to have much data to offer you.

18. What is the proper way to gather beargrass?

    I do not share that knowledge with outsiders. We are only now reclaiming this precious practice and it is too vulnerable at this time.

19. Who gathers beargrass?

    Tribal people

20. Do you gather beargrass for others? Who and Why?

    Yes, I gather it to gift to my future students and as gifts to other Indigenous weavers. A gift of Bear Grass from our Ancestors is a high honor to share with another weaver. If it is one of my students, it is a way to connect them with their grandmothers and grandfathers. If it is to an outside tribal person it is a way to extend that honor to them in gratitude of our relationship and in the hope that the Coos, Lower Umpqua, and Siuslaw will be remembered and present in the baskets they make.

    I also show seasoning Bear Grass in exhibition. I publicly display seasoning weaving materials to the mainstream to educate the public that we are alive and practicing our culture, to share with them the sophistication of Indigenous life. I use it as a political statement to claim public land and space through seasoning these materials in public where in historic times I would have done it on our land itself. I also to it to begin a conversation, to show another aspect or way of interacting with the land that is sustainable, and consent based. I do it to light a fire in the public record of the importance and dire timeliness of land and water protection.

21. How many leaves would you need for each type of basket? How many plants might this represent?

    Each basket is different, each motif, etc. That is an impossible question. Further, you would never take an entire plant, only a small part of any one plant. The amount of leaves on one plant would cover hundreds of baskets.

22. What else, besides gathering leaves, might occur while at a gathering site and at this site throughout the year?

    This is also a sort of classroom, I am teaching my students who are with me and the plants are teaching us. We visit the gathering sites throughout the year to communicate with the plants, pray, check in on how they are doing and see if we need to care for them in any way. By doing this throughout the year we can see how the seasons are changing and be ready when it is time to gather, since each year things change.

23. What is the proper way to care for and manage beargrass and beargrass gathering sites?

    In our contemporary times our land management strategies are severely inhibited by outside (State, Federal, and Private) interests in many of our traditional sites. Our Bear Grass gardens are on State lands. Fortunately, they happen to be in a protected area, so they will not be subject to disturbance by construction, etc. and we have rights to use the space and gather the plants uninhibited (kind of). That means, we can gather there but we could not say, use burn management. The kind of management we do is to remove liter or trees or such that might have fallen on the beds and keep the beds hidden from view by blocking any trails to them that may have emerged in our absence.

24. **<u>What kind of beargrass leaves, or which leaf characteristics are most desired for use for each type of basketry?</u>**

See question #5

25. **What are some undesirable leaf characteristics?**

See question #5

26. **What can be done to promote leaves of the best quality?**

I am told fire maintenance.

25. How do harvest, fire and shade influence the quality or abundance of the plants?

See question #5

26. How has the relationship of your community to fire changed over the course of your lifetime and even through past generations?

I cannot speak for my community but I was raised to know fire as a healthy part of the natural cycle of our natural environment. I witness man's interruption in that cycle to be catastrophic when that natural event overcomes his urge to stop it. If we would respect that necessary part of the cycle and develop our ways of life around that need then we could side step this horrific loss.

27. How has climate change [including changes to temperature and precipitation] impacted this plant? How do you think climate change may impact the plant or access to the plant in the future?

    The gathering time changes from year to year. Everything will change in so many ways we cannot even begin to understand.

28. When do plants flower and under what conditions? How does flowering relate to harvest, fire and other site conditions?

    To the best of my knowledge, they flower in high summer. I am unsure how that relates to conditions.

29. How might scientific research support or not support tribal needs with respect to beargrass or other wild-gathered plants?

    That is tricky, we have our own scientific research, outside research always serves outside interest.

30. How could government agencies or private land owners best support tribal weavers?

    My goal is that future generations do not need “permission” from these governmental agencies to follow their inherited lifeways (gathering, etc.). At this point in our cohabitation, we are working to educate these entities that we will be exercising our sovereign rights to gather and practice our traditional activities on the land and in public spaces. We are also working to teach our future generations of the holistic protocols of gathering and land interactions so our presence and relationship with these places and resources will be healthy.

A second tier of my vision is that significant spaces be returned to the Tribes and removed from “public” activity. There are so many of our sacred sites that are currently used for public recreation or industry. It is a spiritual affront to share these spaces and to witness the devastation that many of them endure for the profit of non-Tribal interest. The only way these spaces can heal is if they are returned to their ancient stewards and the prevailing governmental entities financially support the repair of the land. This would include removal of refuse and contamination left behind as well as retraining their people and the public that these spaces are no longer public and or economic opportunity for non-Tribal entities.

The last component of this vision is Tribally directed mainstream educational opportunity. Once we have had these lands returned and repaired, once we have several generations of healthy and positive interaction with our sacred spaces, we can vision and activate new ways of educating the mainstream from our perspective and experience. The model that will be created that begins with reparations, respect, and support will be a collaborative history that we will all be proud of.

31. What have you noticed about Native youth interest in basketry? If necessary, how would you recommend increasing engagement of Native youth in basketry?

In our weaving program the youth are the key members, although they do not know that. My goal is that when they are adults they do not even remember learning to weave; it is just a part of everyday life.

The first wave of teaching my community to weave was directed at the adults, a “training the trainers” model. Due to displacement and other hardship, we did not grow up together, many of us were meeting for the first time in those early classes and we needed to create our adult bond and vision together. Further, learning to weave is HARD, and so is parenting. I needed uninterrupted days with my students so they could get the basics down. In these classes we were speaking of our Tribes holocaust and attempted genocide, heavy political ideas, philosophy, and contemporary events. We needed this to be a meeting of the minds and hearts to hash out these heavy, heavy topics and connect as adults, unfiltered for young ears. My students would need time to decide how they would parent with this history and contemporary agenda.

Outside of class, my students were encouraged to share all of this with their children as they saw fit. They all did that in their own ways.

Two years ago, the children were included in the workshops, beginning with gathering. As a safety protocol but also to heighten the gift of inclusion, we limit gathering trips to one child per parent. In this way the child feels they are being elevated and privileged individually. They each get that very special feeling of being singled out for an honor, their first gathering experience with the Tribe.

For studio weaving workshops all the children are included. They connect with each other and are steeped in the practices and conversation. It is a total joy to witness the natural way they are growing up in their culture, it's Legos +Spruce Roots+ Barbie's +Bear Grass +monster trucks+ absent minded humming of traditional songs. At our last workshop I brought a large (10 gallon) tule storage basket filled with a few years of scraps from all the materials we use. I dumped it out on the floor and had the youth sort through it. They knew every plant in the mix, sort of grumbled about it too, like "that's cat tail, duh!" totally unaware of how much they knew or how special and bitter-sweet it is to be the first generation in 170 years to grow up this way.

The last way I am seeking to engage the youth is through regalia. All our tribal material wealth items were stolen or destroyed. I am working to rebuild our community cache of these items. This year I am focused on making dance caps for the youth who come to weaving workshops to wear at Salmon Ceremony and Canoe Journey. I want them to stand out in our community as our weaving future. I want to honor them publicly for what they are learning and will carry on. I also want to inspire other Tribal members to join in the work and joy of carrying on the culture. It is my hope that by the time they have outgrown these caps they are making their own and there are new young ones to wear these caps coming up.

32. How do you pass knowledge about beargrass care, management and uses to younger generations?

    They gather it (which includes academic, spiritual, scientific, craft and daily conversational training), help to process it, can identify it both in the field and studio, and they wear regalia that is made with it. One day they will weave with it.

33. What are the most important things to be taught by mentors that should be learned by students in locating, harvesting, processing, and using beargrass?
    I do not believe that non-Native students should be gathering Bear Grass. I believe that Native students should work with Native mentors in the manner that those mentors see fit.
34. How could formal school curriculum best support tribal needs for education of Native youth with concern to significant plants?

    They should hire Native teachers to work with Native youth.

35. **<u>What are your recommendations for strengthening cultural traditions related to beargrass?</u>**

I recommend that it is used by Tribal people in any way they see fit, that is between each Tribe and the plants.

Transcript 2:

Interview with Dr. Frank K. Lake
Date of interview: 08/15/2018
Completed over the phone with Frank reading and responding to questions submitted by Georgia Hart-Fredeluces
Transcription completed by Georgia on 11/01/2018
Edited/Corrections by Frank on 07/08/2019.
Edits/Corrections incorporated by Georgia on 07/08/2019
Text in brackets added by Frank K. Lake
Text in parentheses added by Georgia M. Hart-Fredeluces

Begin transcript:

GHF: Okay. So today is August 15th and I am here with Dr. Frank Lake. Maybe you would like to start by just introducing yourself and saying where you are from.

FKL: I Frank Kanawha Lake, Forest Service Research Scientist and cultural practitioner of Northwest California, give Georgia permission to use this information for her dissertation research and other related works. Today is Wednesday August 15th, 2018. Again, Frank Lake, employed with USDA Forest Service in the Pacific Southwest Research Station, Fire and Fuels Program. My work is almost exclusively in working with tribes around the effects of forest management, climate and wildland fires, how that effects tribal uses, values and interests, especially around ethnobotany, traditional foods and basket material. My age, I am 46. I am male. I am considered a Karuk descendent. Mixed descendency of several tribes, Mexican and White.

FKL: And, I guess the point for the interest of today is my relationship with basketry started as a child and growing up amongst the Northwest California Tribes, primarily Karuk and Yurok. My father remarried a Yurok/Karuk woman, my mom is Mexican-American. I have half-siblings [two sisters/one brother] who are Yurok tribal members and I got the Karuk through my grandfather, my father's father's side. For us, for basketry, that's just a main part of the culture. So, I grew up seeing baskets, being with people who were weaving baskets. I remember my mom saying as a side story, when she was taking the basket weaving classes, as a non-local Native woman there, my dad would pressure her to always take the cultural classes there [at Humboldt State University, circa early 1970s] . She worked for days on a basket and came in the room one time and being as I was so quiet and she said, where's Frankie at? And I had very carefully undone many of her rows of her basket.

GHF: Oh my goodness!

FKL: It stays as a family story and also kind of a joke amongst weavers, if you don't do a very good job you have to rip it out and keep going and weave it right, so I got my early start, I guess, taking apart my mom's baskets.

GHF: {laughs}

FKL: And then more as an adult, and since I am an Oregon State University graduate student, working with the Karuk indigenous basketweavers and then the California Indian Basketweavers Association Members, and I have still learned to gather and process and kinda weave, but mostly on the where to find them, how to process them, what's the good qualities, for many different basket materials.

FKL: Number 2 (referring to question 2), my relationship with beargrass had been for a large part of my life seeing it used in the baskets, the regalia. Having gone out and collected a little bit as a child, but more as an adult, particularly with LaVerne Ferris Glaze. She is Karuk and Yurok--out of the Karuk indigenous basketweavers. It was really was LaVerne who got me more into beargrass and going out with her and gathering and particularly from the Northwest California tribal perspective, the forest management and fire and fuels work that needs to promote access to high quality beargrass and then that relationship with our scientists such as Dr. Susan Hummel, on what are the basketweavers' preferences for beargrass site conditions. So I have developed quite a bit of research around working with tribal basketweavers or practitioners in California, Oregon, and Western Washington, around these management needs for cultural purposes, particularly basketry. I also gather beargrass and use it. I've made the braids. The two leaves braided together, for dresses, for especially long beads on necklaces, and using the men's regalia as filler in the Brushdance men's headrolls that we then sew leather and different bird feathers on. So, I use it. Still gather it. Using it here or sharing it with my Yurok family on the coast.

FKL: How abundant and accessible is beargrass for you, your family and your community, number 3. It's improving. In part, this is thanks to the Forest Service and the partnerships, like the Six Rivers National Forest or the Orleans Ranger District, Roots and Shoots project, burning beargrass. The Orleans Ranger District has a record here of doing beargrass management, all the way back to the 1980s, with the basketweavers.

FKL: Number 4, has beargrass abundance and accessibility changed over time? If so, how has it changed and what seems to be the reason for the change? I have alluded to some of that. The basketweavers particularly came out, beargrass, based on the northwest California culture weaving criteria, is better the one year after it's burned, when you have the supple, flexible, long leaves that are one year post-fire. So, in that case, the high-value interest of the basketweavers working with the local Forest Service Orleans Ranger district has promoted beargrass burns. And it seems to be, that's been the change, that you see more timber stand improvement. There's a growing interest in supporting tribes, especially for their use of the forest products like beargrass. And what seems to be the reason for the change? It's just increasing that ability, greater partnership, increased Tribal-Federal government consultation, communication, and coordination on projects, and then also the Orleans Ranger District Six Rivers National Forest wanting, you know, really supporting tribal interests and values, promoting that through their fuels and fire management and forestry management.

FKL: Number 5, Is there a proper way to gather beargrass? If so, what's the proper way to gather beargrass? I was taught culturally, and also my research as a community forestry graduate student working with the weavers, that there is a proper way to gather beargrass. Not only does it have to do with the site conditions, but there is cultural protocol, for introducing yourself to the area before you gather, offering a song or some kind of other offering, typically tobacco or wild celery root, *Lomatium*, some kind of way of acknowledging that plant's stature/ status as a spirit being you typically use and have a stewardship responsibility with as human spirit to plant spirit. And so the proper way to gather that is kinda spiritual conduct, not taking too much from any one plant. If there are several different whorls, I have seen like up to a third of those taken, and the way that they gather here is that that center pack whorl, usually that year after a burn it kinda comes up like a thick bundle, almost like a jumbo pencil-size, or pencil-size in diameter, about a centimeter or so, yeah, about that thickness, and you basically pull that out. You should reach down in the middle of the clump and a slight tug or pull and it should come out easily and then you somewhat have to thwap [sound of hitting the end] the end of that bundle, like a little fiber whorl there at the end. So, you harvest it like that and there is also a traditional story that I was taught about frog woman and how she tried to harvest her beargrass in the wrong season and not in a burned area and she tried to pull on those tufts of leaves and she cut her hand and so the outer leaves of the whorl have kinda of a tinge of red to them. Based on northwest California cultural weaving, amongst the Karuk and Yurok, you don't use that stuff, although I have seen it used by the Yakima and tribes farther north that have a different weaving technology. For us, the proper way to gather beargrass, is to grab that center tuft, not the outer leaves of the whorl, and then there are the ways in which you have to sort it. The bundles are laid out and it dries in the sun and then after it's bleached white with the sun, and then storing that. So, there is not only a proper way to gather, but a protocol in preparing it and in how you store it, and its sensitivity to light and its yellowing after that.

FKL: Who gathers beargrass? I would say primarily women basketweavers, but also sometimes younger men or men who help their female relations or friends gather beargrass. You also asked in number 5 about the proper way, there is also criteria about leaving the low gradient flatter areas off the road, nearest to the road, for elders, and then us younger men and more able bodied adults and teenagers will go farther up the ridge or across the forest to the openings to pick the beargrass and leave the stuff near the road for elders. So, back to number 5, there is also a proper way of being aware of where you are gathering it, related to who is gathering it because if you have elders coming in behind you, leave some of it right by the road so they can get out there with their cane and still gather it.

FKL: Do you gather beargrass for others? Who and why? I have already answered that. Yes, I do. I gather it for my own uses, but also to share it with others, particularly my coastal Yurok family, that might not be able to come over to the hills, and also, a lot of people don't have the knowledge of what area burned last year, how severe it was or the growth conditions promoting that good quality beargrass based on the cultural criteria, for long, soft leaves. So, since I know that as a scientist and not as a cultural practitioner, I often share that. And so, in that process, I share that with them, and why, because they want that material and its better for their uses. Also, it's important to make sure that a lot of the weaving classes, for the elders who are teaching weaving, to have enough material to teach the younger generation. So, I try to also supply, if I have extra, to them.

FKL: Number 8, how many leaves would you need for each type of basket? How many plants might this represent? Oh, I don't know. I would say it depends on how many turns and twists, the size of the basket, the surface area, you could do a calibration between the width of your weave, and the root you are using as the beargrass overlay on that root for a design, calculate how many millimeters you need of that per basket, but I don't weave that well enough to know.

FKL: Number 9, what else besides gathering leaves might occur while gathering at a site and at the site throughout the year? So, that's an important thing to teach. Formerly I worked with Dr. Hummel and working with the Siletz and Grand Ronde up there in the Oregon Cascades was, when talking to some of their experts, I started describing, like, what is the criteria, so that when you are teaching another person, how do they know what to do and why. And so, in that regard, you know, it's about knowing where beargrass grows, what kind of climatic or weather patterns or seasonal precipitation might affect how it grows that year, what the forest stand is like, based on tree density, how much light there is, the accessibility, this is all in the paper we published in the Journal of Forestry and other related things, but it gets down really to how do you access the site, how do you first locate the site, how do you access it, when you get to that potential area where beargrass is growing along that road or ridge feature right there, then what's the potential gathering area. Some places, a lot of people are culturally taught by an elder or a weaver that they go out with and then they go back to those same places, but without the frequency of fire and without the rotational burns, that get in certain areas, now you are more less, as say the weavers in California, "following the smoke". You see wildfire or a prescribed fire someplace, and you have slightly beargrass habitat, you go check and see. So that's part of what people usually do when they are gathering, you know, you might be there at early summer to see how the beargrass is growing back. You might also be looking for other wildlife. You might be getting some spring medicinal plants, and then there closer to the summertime when you gather, you are looking at wildflowers, you are checking out the burned area that also happened there the year before or two, and then you are getting the family together to say, here's a good day we can get the family together and go have a picnic and gather. And then, I might, also, as a mushroomer or hunter, go back to some of those places because I have actually hunted deer, seeking out bucks, in areas that are burned the year before, two years. So, some places where I am gathering beargrass, I will see a lot of deer sign, deer droppings and browse, and I will come back there to hunt in the fall, a month or two later. Or sometime later, given the time of the season of hunting. So that's the things there, associated with beargrass.

FKL: Number 10, what is the proper way to care for and manage beargrass at beargrass gathering sites? Well, I guess proper is a more subjective term, but there's kind of conditions that are ideal. And so, the way to care for it is, 1: there is tribal philosophy that you never gathere more than you can use, you always allow something to have the ability to reproduce. So you make sure it is in flowering or vegetative reproduction across the site. And then, you limit how much you harvest from any one plant or within one area. So you got to do skips and gaps and maybe even along a three mile ridge area that burned, maybe you hit ten different places along those three miles, you are not just concentrated on one place. And, again, if it's close to the road and flat, leave that for elders, there might be some good beargrass up on a bench or a little ways up the ridge. Go check that out. And then, the way to care for it is more around the forest management, and for our cultural, our tribal preference down here is to have it burned. It can be a lower intensity fire, it could be a little bit moderate intensity fire, but you need the filtered light, or a canopy above at these sites so you can get those biophysical or ecological conditions right. And then there is also this belief that when you are there gathering, it's also your interaction as a human being at that place with those spirits of the plants and animals that is forming and maintaining that relationship or that reciprocity. That's like part of that proper protocol.

FKL: Number 11, what kind of leaves of which leaf characteristics are most desired for each type of basketry? Really, my knowledge of northwest California is that it is those internal, thinner, not so wide of a leaf, ones in the whorl bundle in the middle. Ideally the characteristics are those that are soft, supple, don't have a cutting edge on them. And I would say, yeah, there are certain criteria that also goes along with if you are weaving a wider weave, if you are going to use it for the braids, or if you going to use, like often when weavers gather there is always the bigger material, or those stained with frog woman's blood. I would use those for stuffing the Brushdance men's headrolls or other regalia not in the basket weaving. There's different types for basketweaving, but also regalia, there's characteristics that you want. One of the main things I heard about is, the prominence of that midrib on each leaf and how that can be a little bit of a consideration in how they flatten them or split them down and use then for weaving. That's more on the weaver's side.

FKL: What are some of the undesirable leaf characteristics? Well, you don't want the thicker, older, coarse leaves, the ones that have crickets or grasshopper bites on them, if they're too stiff they have like a papercut edge, that's not desired, there is kinda that spectrum from what's undesirable to what's desired leaf characteristics. At least down here in northwest California, it's more of those longer, softer leaves, off the center, and their width and they have to have the full length of them, can't be like chewed off or have little cricket chew marks on them, that's not going to make it good. If it's too stiff, with the prominent midrib, then that's not desirable either. At least not for weaving. You might be able to use them for something else, but not for overlay material.

FKL: Number 13, what can be done to promote leaves of the best quality? I think part of that just has to do with environmental and individual plant growth characteristics. So, I know, when we had the droughts here, the last couple years between like 2012 and 2015, the lower soil moisture was really hard on the beargrass plants, even in the burned areas. So, relating soil moisture back to the high quality leaves, that kinda sound of the squeak when they get pulled out, and they are moist at the base down in that whorl, where you detached it from when you pulled it, that is something that can be done for the best quality leaves, just look at the plant vigor. Also, its amount of light, if it's been browsed or not, part of that also has to do with the herbivory from deer, elk, crickets, things like that that might be indicators if one of those insects like a cricket chews on it. So you are weeding stuff like that out to get the best quality leaf, in the plant, in its growing site.

FKL: Number 13, how do fire, harvest and shade influence the quality or abundance of the plant? I already spoke about that a little bit, but it's really the biophysical conditions that relate to the criteria of how that individual plant you are going to harvest from is growing within the forest. But also, whether or not that forest site had been burned in that year or two prior, and if so, at what severity or intensity. Then, usually when you harvest it, you're not taking too much from any one plant, you're kinda skipping between individuals, leaving some, you're also kinda evaluating the color hue, that blueish green, that Susan and I were able to use a Munsell Color Chart to kinda home in on as a general characteristic. The fire, preferably down here [NW California] areas that are one year post-fire, that had a lower to moderate intensity burn, where there are still overstory surviving trees left, I would say about 40-70% canopy closure, and then shade is a part of a factor, but it also has to have a little bit of light. But some of those beargrass growing down here do better on those bigger Douglas Fir, pines, and don't have too many shrubs like rhododendron, Saddler oak, chinquapin or other shrubs growing in there, Ribes [Gooseberry/Currant], who can poke you, trying to really look at a site that usually when it's one-year post-burn you killed those top shrubs, and you cleared out some of that undergrowth fuel, so you have better access and visibility as to how the plant's responding and that really affects its quality, but you can look at the vigor from just the plants, that has nice long leaves, that has the right blue-green color, and it looks like it has the quality that you want there. Abundance really has to do more with the density. If they're just kinda sparsely populated, you might want to not pick so much, if it's a thicker patch, then you might work your way around different sides, or take a few steps, gather a little more from that particular one, kinda work your way across the patch.

FKL: Fourteen, how has the relationship of your community to fire changed over the course of your lifetime, and even through the past generations? I think more importantly, here in northern California, with a very frequent cultural fire regime, where tribes were burning a lot of the landscape and particular to beargrass, maintaining those open ridge systems. And a lot of those open ridge systems, where beargrass grows, and I have done historical research, to show, interestingly enough, that a lot of those main trail systems, between like the Yurok and the Karuk, that went through the mountains between each other's territory, are on these prominent ridges that face the Pacific Ocean, with that coastal influence, but are on the edge of that more interior dry of the Klamath river corridor, and so those used to be more frequently managed. Then with the creation of the Forest Reserves, then National Forests, fire suppression policy and fire exclusion, they weren't able to burn so much. So, that really changed the role of fire use and stewardship. It went from being intentional burning to promote beargrass, to being open forests where beargrass grows, to being then more dependent upon lightning fires, and/or then after the 1960s, 1980s and timber harvesting, if there were areas that were harvested by the Forest Service, and then burned, then sometimes basketweavers would opportunistically pick in those areas, and now, up until the last couple years, with exception of a few of the 1980s projects, and some that were done this year more recently, with the Roots and Shoots, last year, June 2017 for the Orleans Ranger District, it's pretty much just following wildfires. If a wildfire happened to burn in an area that had beargrass, you would go check it out. So that's kinda been the adaptive response, but now with greater cooperation and coordination and consultation of tribes, between the Forest Service and tribes in consultation with the basketweavers and organizations, there's increased interest in integrating that tribal knowledge and ethnobotany or basketry use for beargrass into the landscape restoration strategies. Informing the crews who are out there doing the fire suppression or the fuels work about how to manage and try to promote beargrass, and not to hurt it. Even down to when they are doing the ignitions on the prescribed burns, is like, hey don't use your drip torch [diesel/gas mix fuel] on the plant. Drip it on the Douglas fir needles/twigs, and the leaves and needles around the beargrass clump and let it back into the plants. So that way when the basketweavers harvest it, they are not getting anything that was actually directly tainted or burned with drip torch fuel. So there's those kind of other considerations, of how I've seen that change. But, you know, in the big picture, it used to be more family, sovereign kind of fire burning, and at that level, and now it's more of tribes and basketweavers depend upon the agency or a cooperative burn between agencies and the tribe to do that. Otherwise, other people do it covertly, or do patch arson burns, which I am aware of. With their Bick lighter or a propane burn, and you singe the beargrass, and then you just douse it out with a bucket of water, or your little thing of water, and then you still get a couple of plants burned, and so I know people even practice that, without setting a forest fire, they just burn individual tufts, to cause that batch to renew, just on the down low. So, people still do that, but now more the Forest Service burns are a little bit accessible, the burns are specific for the beargrass, not in response to wildfires.

FKL: Number 15, how is climate change, and including changes to temperature and precipitation, impacted this plant? How do you think climate change may impact the plant or access to the plant in the future? Well, just considering the preference for the best growing beargrass conditions biophysically here in the western Klamath Mountains, is those ones that are kind of maritime influence, coastal fog coming inland. Also, having some snow, but not a whole lot of snow, it could be anywhere from 3-6 feet, but not frozen lakes like the higher elevation Rockies or Cascades are, our coast range, and so there has been changes in the warming conditions, the temperature, which also affects the plants' growth, the phenology and physiology, with the droughts that we had, that were more persistent, a lot of California's Mediterranean climate, that can have an effect on the plant's vigor, especially if it has been a persistent drought, like of three to five years we had recently, the last couple of years, precipitation is changing also, a bit, so whether that's the snow level in elevation, how much snowpack there is and then when that melts off, those plants are exposed and able to grow for their season in late spring, through the summer, that also affects it, and even the fact that we are having later fall rains means that there is a longer amount of time, especially if the fog is changing, that you don't have that soil moisture and precipitation influence, on the plants. So, I think that's affecting it, how people are seeing that what used to be a lush, vigorous patch, now kind of declining. I think part of that was the drought, but then also with the increased temperatures and the lengthening of the fire season, you have conditions now where areas that might have been more frequently burned by families, pre-fire suppression, now have thicker forest, heavy fuel loads, much more duff and litter and logs and branches, and when fires do burn at the most extreme conditions of the mid to late summer, then you have high severity and you are literally cooking the soil and killing the plants directly because of too much fuel on them. Not only were they smothered because of too much fuel in the absence of fire, now they are completely consumed and burned and you have lost patches of pretty good beargrass gathering because of that. Other impacts are that, it does require some bare mineral soil to reproduce/for seeds to germinate, so some cases where there are these crown-torching or little small patches of high severity, that has its place for rejuvenation. But, when you see that happen over contiguous areas, like subwatersheds or hundreds of acres, it has affected where and how gatherers chose to gather, and if there are areas that have been long established as having a few Forest Service burns. There was one done in an area in 2005, and then you had a wildfire come through there in 2008, and that was a high severity one, killed all the trees. Last year there was another fire in that area, just up the road, so then they had to cut all those snags that were in that former beargrass gathering area, that was burned a little bit too cool in 2005, had high severity fire in 2008, and another fire was coming through there in 2017, and then they had to log out and get all the equipment and clear all the snags because it was adjacent to the road. And now it's pretty much just a, what was formerly pretty good beargrass under old growth Douglas fir- pine forest, is now basically a brush field of young firs, and *Ceanothus* and hardly any beargrass. And I see those kind of changes in forest management, or the legacy of forest management, the effects of climate, and the increased intensity and severity of wildfire in a more maritime or coastal influence, forest types, that is affecting, in one or two generations, the perception of what is a gathering site and it being traditional, versus now, like, oh, this area is impacted by wildfire, we have to find new places. And so I see the struggle most tribal communities, like, I have always been taken to this place and I have always gathered here off this road, that place has basically been high severity affected, it's not going to recover in my generation, in 30, 50 years, and so where do we find other places? So, there is that part of that coping and that process, of like, where's the next suitable place that we could get it?

FKL: So, how do I think, is that part of question 15, how do I think climate change will impact the plant and access to the plant in the future? Well, I guess I talked a little bit about that was that fires burn with more high severity and you lose the forest structure, that overstory, and big trees, some of it might have heavy fuel loading. But other places, if it's the adjacent fuel-loading, there's been places like that one I just described, it had been burned in 2005, but even the wildfire extreme conditions of the dry east winds, in the next fire in July 2008, a couple years after, that it completely changed the site. So, I don't even know if that is a suitable gathering area. That place across the street, I mean, literally, 100 feet across the road, is better, but that was the fire line and that is where they were able to stop that 2008 fire from getting to there. So, I think in the future it's going to be, in my work as a heritage resource advisor, and as fires burn in these areas that have beargrass, it's working with the fire suppression crews, the tribal heritage consultants, like resource advisors, in consulting the basketweavers and say, hey, if this area burns, what would you like to see here. And I advise them to do a burn out here and do a backfire after you use that same road, where you like to gather as a control feature, fire line. What kind of fuels work would you want done there if they are doing it during fire suppression or a hazardous fuels reduction project? That fuel-loading and effects of influencing the overstory tree density relate to the understory plant condition. And all that information has to be fed in, to inform your activity in fire suppression or in your active management, the fuels work and re-introducing fire through prescribed fire. So that's a lot packed in there, and also I think it's gonna be, as we see changes in moisture, particularly with the snow/rain levels, with fog, and here in northern California, that's going to affect the plant's growing conditions and you may even see, phenologically, a shift earlier seems like. People usually gather it more in mid August, late July, now it's more mid-July, early July, as we lengthen out the summer, then also the plant's phenology is going to shift forward, seems like, with the soil moisture and growing conditions, and that's also going to affect peoples' timing of gathering of the resource. So, there's all those things in play that I try to articulate through, this is how climate affects forests, effects a cultural use species, that affects the knowledge system and practice, as exampled by a basketweaver and beargrass.

FKL: Number 16, When do plants flower? Under what conditions? It's always been my understanding that there is a little bit of sporadic natural flowering, that maybe has to do with soil moisture, or maybe how cold the winter was, something like that, some biophysical or ambient air temperature stuff, but generally, the flowering is more likely to occur the second or third year after a burn. And the profusion of all those blooms in an area is like two or three years old after fire. And, how is that related to the harvest? In some places where there has been timber harvesting, they've opened up the understory, you see some plant responses, but if they tractor-logged it, that usually has more damage and the beargrass is less likely to recover. Other sites, I saw areas that burned high severity, I thought the beargrass was knocked back pretty good, but then again it had more seedlings, in the three to five years or even seven years after the burn that I saw, versus the vegetative off-shoots of this expanding new whorl on the side of older plants. So, I saw that kind of interesting dynamic change where reproduction and kind of maintaining site dominance, after a high severity burn, that had more bare mineral soil cooked it pretty good, you seem to see another flush of seedlings, little ones, but then those are soon, like five to seven years after fire, those are soon overgrown by the firs and the shrubs, like *Ceanothus* growing in. So that, unless you would have gotten another fire in there, which did happen, that pretty much type converted that patch, more beargrass to and prince's pine, Oregon grape and things like that, the small amount of shrubs adapted. You pretty soon see a sea of, a continuous carpet of young fir and shrubs like *Ceanothus*.

FKL: Number 17, how might western scientific research support or not support tribal needs with respect to beargrass and other wild gathered plants? Well, I'd like to think that researchers like myself and you as a graduate students would help create the best-available science, respect the integration of traditional knowledge into the way we do our research, how we formulated our questions, how we did our methods, how we interpret our results and communicate those results, so I think it can support tribal needs. And with respect to beargrass, it's a highly commercial as well as culturally important one, for the floral market and also for tribal weaving traditions. And I think the more that we come from a practitioner-centered perspective of what the science support needs or researchable questions are, then the more likely we are going to be able to serve those tribal people. The botanist, who is trying to manage for beargrass, because it's like, oh, I heard there is a value for it with the tribe, is a lot different than having that perspective of a weaver, who has decades of harvesting at different sites, in different conditions, of knowledge, and how that responds and how they use it, and inform the way we go about forming our research study, or how we do our monitoring.

FKL: Number 18, how would government agencies or private land-owners best support weavers? Well, in the case of the Forest Service, they have a government-to-government relationship to consultation, coordination, and communication on planning projects together. I think they also have certain authorities, like the Farm Bill, Chapter 32-A, the Culture and Heritage Cooperative Authority for tribal harvesting of forest products for traditional & cultural purposes. So, there are these authorities and policies that promote tribal access and use of the beargrass on national forest land. Also, there is the California, for the Bureau of Land Management, BLM, the California State gathering policy that the California Indian Basketweavers worked on that is for free use to harvest and collect beargrass on Forest Service and BLM land. The National Park Service, under the Department of the Interior, has another similar set of policies and authorities, they just revised their, what do you call it, Special forest products rules. The Yurok Tribe requested me to speak about the park research on the quantity and harvesting methods for some plants. So, the park service is different. And then for private land owners, the number one threat and concern down here has to do with industrial private timberlands. And how they use herbicides and how they plant monocultures and they give little regard to cultural use species like beargrass. So, the more that you can actually have private timber companies be more innovative and considerate of the way they do their reforestation, or the way they grow their crops [tree plantations], and the way they provide access to those private forest lands, within a tribe's ancestral territory, which might be somebody's traditional use area, historically, and have an interest to be there, involved in that landscape today, those are all negotiations and relationships that need to be worked on. So, that could be improved. But the greater awareness through our research, through their voices and newsletters and basketweaver gatherings, where people can learn to be educated from a basketweaver's perspective, about what the needs are, the more that is going to be converted over to the manager's hands, and have hopefully a beneficial effect on the ground.

FKL: Number 19, What have you noticed about Native youth interest in basketry incorporating beargrass? How has interest changed over time? It has always been there. At least, working with LaVerne when she was alive, she taught here, Orleans elementary, Verna Reece from Happy Camp still teaching basket camp on Sundays, comes down to Orleans on Thursdays, there's use. Use can be from little kids going out to harvest, and, you know, burn down the forest and learn about the right way to harvest it, to being the teenage woman, who has, as part of her coming of age ceremony, requirements for learning to weave to make her regalia. Same thing with the young man, learning how to help the women and support them. So, I think there are various cultural knowledge and traditions and practices that go along with teaching the youth that can be centered around just basketweaving and beargrass, and then it's also, the part as you get to be an adult, how you engage in the forest management and fire management, that will promote access and high quality sites, for beargrass, for the rest of the community and weavers. And so, I have noticed youth continuing on with that, and a lot more tribal programs that focus on food security also have under that umbrella basketry or other uses of forest products and they are teaching that and making sure that is entered in the school curriculum, as far as their summer youth camps, and opportunities to go out and do more fieldtrips and have youth engaged.

FKL: Number 20, How do you pass knowledge about beargrass care, management and use to younger generations? I do it through the basketweaving classes. I provide my little handouts and things about beargrass management and uses. I give it when I am using beargrass, making the beargrass braids, or making a [Brushdance] headroll for men's regalia, even that stuffing. So I teach that way, but most of it I think is just being right there and being involved with these Forest Service, Tribal kind of volunteer camps, like "Follow the smoke, passport in time," or the Tribe's food security or other workshops they have.

FKL: Number 21. What are the most important things to be taught by mentors that should be learned by students in locating, harvesting, processing and using beargrass? I think the most important thing is where you find it. First biophysically on the landscape, what makes good access, what makes the good kind of forest condition, what makes beargrass likely to be the best growing condition of like the moisture, the tree cover, the amount of light coming in, how much fuels or understory brush or other vegetation there is. So teaching all the best places where to find it, how to locate it, and then when you are actually out there, you are helping them understand like yes, this is beargrass growing here on this serpentine site, but it is such a scrubby, harsh soil, and so much sunlight, there is no way you are going to use this beargrass. It is never going to be marginal or even good. It's always going to be poor growing conditions, so, don't waste your time with beargrass on serpentine, but if you just go a few miles over here on this shale schist, on this red clay, there's this soil type and there's older growth forest with big trees and you know, you teach where you find it and what kind of conditions, basically teach what are the best places and where you don't want to waste your time in. So, I think that's part of it. I think also, the whole thing about respect and reciprocity, and introducing yourself and that kind of that, I am asking for something from the beargrass, what can I do to give back is an important part of the stewardship and more that spiritual aspect. I know that for other tribes and also the way I was taught in my family, the harvesting is a big part of it, and the processing of it, you can do it by yourself, but I find there is a lot more social strength together, when people are around, you know, and you are like, hey, I got a big old thing of beargrass I just got and drying it out in the back yard or something out in the sunlight and you get together and have a few friends help you sort it and like hey, I would like to weave with bigger stuff and I would like to weave with smaller stuff and see people kinda divvy up what they have and here's getting together and many hands, light work and putting that process and for sure a little story and you have a little transfer of knowledge in the process of preparing your beargrass. And then when using it, there's going to be all these little subtleties of which ways, like I know a weaver who was weaving it around her conifer root as overlay design where that midrib or that prominence of that, how that beargrass lays on there, which side of the beargrass you are using, whether it's the top side or the bottom side, how much of it you are having to flatten out or scrape, I mean all of that goes into good site, good quality plant, prepared the right way, weaving the best product you can at the end and use.

FKL: Number 22, how could formal school curriculum best support tribal needs for education, native use. I think I have mentioned a lot, increase the awareness that it is a contemporary tribal basketry important species, that there are current tribal needs for forest management, for fire management that promote access and high quality beargrass for use and show in a kinda of respectful depicting way, how beargrass is used and the different ways in which can be anything from these braids that are necklaces and dress material, to the white pattern on the overlay of a basketcap, or on a basket. And then even show the diversity, I think it is also important to show your own tribal weaving specifics, but also show the diversity of how beargrass is used across all weaving technologies and cultures. That was one thing that really opened my eyes up, being so rooted in Northwest California, that when I started working in the rest of the Cascades, up in Oregon and Washington, I see, oh, there is this imbricated style and the Plateau weaving style culture type and how that really expanded my knowledge and respect for the plant and the cultures that use it.

FKL: And then, number 23, what are the values of basketry traditions? What are the values of basketry traditions that incorporate beargrass? Well, it's highly valuable, but it is primarily of value to the tribal cultures that want to maintain that tradition, but I also think it is of value to the rest of our public to our communities who are non-tribal, to be aware that there is this cultural-dependency, this relationship with this plant and this forest, and it's used in this way. And, again, good education, respecting cultural diversity, and particularly the basket weaving traditions.

FKL: And then the last one, for number 24, what are my recommendations for strengthening cultural traditions related to beargrass? Is to have kids put down their phones, get outside, be engaged in things by respecting your elders and doing things with your elders. And then, really, for the basketweavers, or the cultural practitioners who are teaching it, finding ways to support what they need. In both resources, from everything from a good working truck, having gas money, to having a core of people that they can mentor that can go along with them to have that cultural enrichment. And then also on the land management side, providing suitable areas in the landscape that are accessible, that have the right kind of forest conditions, that if there is fire use or a fire management strategy, that that incorporates the cultural interests and values for promoting beargrass and its conditions and then making sure that that is communicated between all those entities involved in landscape restoration or management. Particularly if some of those areas are sensitive or are of high value to tribes, to not only promote their use and access, but perhaps, to find other ways to, under Chapter 32-A, culture and heritage cooperative authority act on seasonal closures, maybe even preventing the floral industry competition or understanding the difference between what the floral industry wants for their arrangements versus what different weaving cultures need for their uses of beargrass and basically finding ways to minimize competition and provide opportunity and access and high quality material to maintain that beargrass-related weaving cultural knowledge and practice.

GHF: Thank you very much. I really appreciate you sharing your knowledge and input on these questions. That was extremely helpful. Is there anything else you want to add?

FKL: Um, covered a lot there. You know, I think there is an important part where I see some of the weavers who use beargrass in their baskets, they sell that and make a commercial profit, or they have consignments, and that is a really important way of them having monetary compensation for their knowledge and their practice. And sometimes people will be like, oh, that person just weaves to sell, but at the same time that person is making a living, and she is keeping the tradition and the weaving styles going. Otherwise, she would be working at the market, or something for the County, or whatever, some job that wasn't weaving. So, I think there is also a place for recognizing the value-added aspects of harvesting beargrass, making baskets and some of the tribal artisans being able to sell that and have that recognition for their work in addition to making what's needed just what is needed to promote the culture. Beargrass is used in a lot of specialized baskets, like down here there is the jump dance world renewal ceremony, there is a very special kind of basket, like a little pouch that is made with beargrass on it and there are ceremonial caps, there's everything else, but just to realize that how important that is for beargrass to be a part of her baskets or regalia, that has very important roles for different ceremonies or traditions. I can even think about how we use beargrass as a little braid around the wrist [or as a necklace] after a family member passes away and that basically deteriorates and as it falls off you are done mourning. And so there is even significance with that. Where, you got me on a hard one here, but, (grieving) if you go out with an elder and you gather beargrass at a place, you go back to the same place to remember them, you gather beargrass and you make your little mourning bracelet [or necklace], every day that you are doing that you are thinking of that place and that person, in my case, LaVerne, you know, like how much she taught me, the wealth of knowledge that she shared so that I could have a better quality life, and so there are little things like that, Georgia, that, yeah, it's just a plant, it's just a place in the forest, and some time with an old woman, but it is such a huge part of life, and enriching. Just really honoring those people that gave so much to you.

GHF: Thank you

FKL: Yeah. I haven't thought about that one in a while, but yeah.

GHF: How long ago did she pass away?

FKL: Last year.

GHF: Oh, so recently.

FKL: Yeah, I still, I was going through my shop yesterday, to make sure I didn't have mice in my box of beargrass. And I thought, oh, I got this with LaVerne. You know, like here's the beargrass necklace with pine nuts that I made for LaVerne that the family gave back to me. Just in a real way there are these little reminders everyday. You know, that woman and how much she loved me and gave me and my family and then I have the little pieces of the beargrass and the basket she wove for me. And my little tobacco basket [LaVerne made me] I use for my prayers, and the necklace I made for her that I got back, and all those little things, and really, you bring up beargrass specifically, but that's just one of them, that is a constant reminder, somehow, of our relationship with the culture, with these elders, with the plant, with the place.

End transcript

Appendix 3.1. Additional Information on Methods

3.1-A: Understory vegetation across sites and plots one and three years post-fire as percent cover by vertical projection. Plots were each approximately 4 x 4 meters.

SITE A								
			unburned		low severity		high severity	
species	common name	growth stage	2015	2017	2015	2017	2015	2017
Trees								
Abies amabilis	pacific silver fir	sapling	10	15	---	---	10	0
Abies amabilis	pacific silver fir	seedling	---	---	5	0	---	---
Tsuga heterophylla	western hemlock	saplings	---	---	---	---	---	---
Tsuga heterophylla	western hemlock	seedling	---	---	---	---	---	---
Tsuga mertensiana	mountain hemlock	sapling	20	20	---	---	---	---
Tsuga mertensiana	mountain hemlock	seedling	---	---	<1	0	---	---
unidentified conifer	subalpine fir?	seedling	---	---	0	3	---	---
Shrubs and herbs								
Xerophyllum tenax	beargrass		45	60	40	30	45	30
Gaultheria shallon	salal		5	<1	---	---	---	---
Vaccinium membraceum	big huckleberry		25	15	75	80	0	5
*Vaccinium scoparium**	red huckleberry		---	---	---	---	---	---
Vaccinium spp.	unknown		---	---	---	---	---	---
Achlys triphylla	vanilla leaf		---	---	---	---	1	<1
Arctostaphylos uva-ursi	kinnikinnick		---	---	---	---	0	<1
Chamerion angustifolium	fireweed		---	---	---	---	0	<1
Chimaphila menziesii	little prince's pine		<1	<1	---	---	1	<1
Chimaphila umbellata	prince's pine		---	---	---	---	---	---
Goodyera oblongfolia	plantain		---	---	---	---	---	---
Lupinus bicolor	miniature lupine		---	---	1	<1	---	---
Mahonia nervosa	dull oregon grape		---	---	---	---	---	---
Pyrola asarifolia ssp. *bracteata*	pink wintergreen		---	---	---	---	1	<1
Rubus lasiococcus	roughfruit berry		---	---	<1	<1	---	---
Carex spp.	sedge		---	---	---	---	---	---
unknown	moss		70	95	50	5	---	---

SITE B								
			unburned		low severity		high severity	
species	**common name**	**stage**	**2015**	**2017**	**2015**	**2017**	**2015**	**2017**
Trees								
Abies amabilis	pacific silver fir	sapling	10	15	---	---	---	---
Abies amabilis	pacific silver fir	seedling	---	---	---	---	---	---
Tsuga heterophylla	western hemlock	saplings	2	2	---	---	20	15
Tsuga heterophylla	western hemlock	seedling	---	---	1	0	---	---
Tsuga mertensiana	mountain hemlock	sapling	---	---	---	---	---	---
Tsuga mertensiana	mountain hemlock	seedling	---	---	---	---	---	---
unidentified conifer	subalpine fir?	seedling	---	---	---	---	---	---
Shrubs and herbs								
Xerophyllum tenax	beargrass		60	45	30	45	15	20
Gaultheria shallon	salal		---	---	---	---	3	10
Vaccinium membraceum	big huckleberry		---	---	2	5	---	---
*Vaccinium scoparium**	red huckleberry		5	1	---	---	---	---
Vaccinium spp.	unknown		5	1	---	---	2	5
Achlys triphylla	vanilla leaf		---	---	---	---	---	---
Arctostaphylos uva-ursi	kinnikinnick		---	---	---	---	---	---
Chamerion angustifolium	fireweed		---	---	0	<1	---	---
Chimaphila menziesii	little prince's pine		---	---	---	---	---	---
Chimaphila umbellata	prince's pine		---	---	---	---	---	---
Goodyera oblongfolia	plantain		---	---	---	---	---	---
Lupinus bicolor	miniature lupine		---	---	---	---	---	---
Mahonia nervosa	dull oregon grape		7	<1	1	1	---	---
Pyrola asarifolia ssp. *bracteata*	pink wintergreen		---	---	---	---	---	---
Rubus lasiococcus	roughfruit berry		---	---	---	---	---	---
Carex spp.	sedge		---	---	0	<1	0	<1
unknown	moss		85	80	40	25	10	20

SITE C								
			unburned		low severity		high severity	
species	**common name**	**stage**	**2015**	**2017**	**2015**	**2017**	**2015**	**2017**
Trees								
Abies amabilis	pacific silver fir	sapling	20	15	5	20	---	---
Abies amabilis	pacific silver fir	seedling	---	---	10	0	---	---
Tsuga heterophylla	western hemlock	saplings	---	---	---	---	---	---
Tsuga heterophylla	western hemlock	seedling	---	---	---	---	---	---
Tsuga mertensiana	mountain hemlock	sapling	---	---	---	---	---	---
Tsuga mertensiana	mountain hemlock	seedling	---	---	---	---	---	---
unidentified conifer	subalpine fir?	seedling	---	---	---	---	---	---
Shrubs and herbs								
Xerophyllum tenax	beargrass		30	30	30	40	30	30
Gaultheria shallon	salal		---	---	---	---	---	---
Vaccinium membraceum	big huckleberry		70	60	---	---	5	10
*Vaccinium scoparium**	red huckleberry		---	---	---	---	---	---
Vaccinium spp.	unknown		---	---	3	5	---	---
Achlys triphylla	vanilla leaf		---	---	---	---	---	---
Arctostaphylos uva-ursi	kinnikinnick		---	---	---	---	---	---
Chamerion angustifolium	fireweed		---	---	---	---	2	<1
Chimaphila menziesii	little prince's pine		---	---	---	---	---	---
Chimaphila umbellata	prince's pine		---	---	<1	0	---	---
Goodyera oblongfolia	rattlesnake		1	<1	---	---	---	---
Lupinus bicolor	miniature lupine		---	---	---	---	---	---
Mahonia nervosa	dull oregon grape		---	---	---	---	---	---
Pyrola asarifolia ssp. *bracteata*	pink wintergreen		2	<1	---	---	---	---
Rubus lasiococcus	roughfruit berry		---	---	2	3	---	---
Carex spp.	sedge		---	---	---	---	2	<1
unknown	moss		90	80	95	40	35	0

*Identification uncertain

3.1-B: Plot selection process and criteria

G. Hart-Fredeluces and field assistants surveyed each fire and visually inspected fire severity, canopy openness, soil characteristics, slope, aspect, and beargrass individual density across accessible parts of each fire. To select plots that would be comparable across sites, I stratified plot selection by slope, aspect, and beargrass density. At each site, using a Garmin 650 Rhino GPS, I walked the perimeter of regions of the fire with a south or east aspect, and a slope between 20 and 45%. The fine-scale map of my path from the GPS unit was hand drawn on graph paper based on the recorded GPS track and then divided into equally-sized areas using the boxes drawn onto the graph paper.

Each section was then numbered, and a random number table was then used to select a plot within the burn. I then used the GPS to navigate us to the center of the chosen square and used that point as the plot center for the high-severity plot. Plots were accepted as a high-severity burn plot if there was at least 10% beargrass cover, at least 100 beargrass individuals within a 4 x 4 meter (m) area, at least 80% of the individuals had burned (rosette base blackened and some leaves burned off), and there was >75% tree mortality. The unburned sites were then selected by walking from plot center to the closest fire perimeter (usually the fire line dug by the fire crew) and walking 20 paces (14 m) perpendicular to the fire line. This plot center for the unburned site was selected if it had at least 10% beargrass cover, with a southeast aspect and slope between 20 and 45%, and canopy openness >10% in some part of the plot. If plots did not meet these requirements, a die was rolled to determine the direction of movement (away from the fire with a 180-degree range of possibilities split into six pie regions) and I walked in the direction rolled until arriving at an adequate site. Low severity burn plots were selected by walking along the same elevation as the high severity burn plot, in the opposite direction of the unburned plot, until reaching a low severity burn area that had at least 10% beargrass cover, at least 100 beargrass individuals in a 4x4 m area, 80% of beargrass individuals were scorched or lightly burned (leaves singed to a white color, but not blackened or burned off), moss was killed but not consumed, and tree mortality was <50%. The criteria I chose were easy to accommodate at all of the sites. In determining fire severity at the plot level, I consulted with the forest soil scientist, the Burned Area Emergency Response (US BAER) soil assessment (Parsons et al. 2010) and published burn severity metrics such as (Ryan 2002). Satellite imagery-based assessment of fires, referred to as differenced Normalized Burn Ratio (dNBR), can often provide this information, but this type of data is not available for these fires because these fires are smaller than the minimum size for inclusion in dNBR assessment.

3.1-C Determining the best proxy for plant biomass

To determine the plant size measurement best correlated with plant biomass, the basal diameter of the individual rosette, the leaf crown height, leaf crown width and length of longest leaf were measured for 30 individuals across a wide size range at three locations. These individuals were then harvested at the ground level. Leaves were cleaned and then a random subsample of each individual was used to determine the total leaf area (L-COR LI-3100C Area Meter). The total aboveground biomass was determined by drying the subsample at 80°C for 48 hours in a drying oven (VWR), then weighing on an analytical balance (Ohaus Explorer Pro). Basal diameter (0.89), followed closely by individual crown width (0.87) had the strongest correlations with both total leaf area and individual aboveground biomass. Basal diameter was also found to be one of the best measures of size in *X. tenax* in another study (Means *et al.* 1994).

3.1-D: Estimation of seed capsule production for partially consumed flowering stalks

To account for seed capsule production of plants with partially consumed flowering stalks, the relationship of flowering stalk basal diameter to capsule production and the average number of seeds per capsule were determined in a separate sub study. In this sub study, I found that the length and the basal diameter of the flowering stalk were most strongly correlated with number of capsules (corr = 0.80 for both). Therefore, for individuals that had partially consumed flowering stalks (observed in almost every case of herbivory), the basal diameter of the flowering stalk was used to estimate capsule production using coefficients from the best fit model (n=32 plants). Basal diameter of flowering stalks was measured with digital calipers at the point where the flowering stalk emerged from the ground, or as close to that point as possible.

Appendix 3.2. Additional Tables and Figures

Table App.3.2-A: Coefficients for main effects and interactions in logistic mixed-effects model for individual survival one, two and three years post-fire, with seedling and non-seedlings modeled together in 2017 (< 10 seedlings in other years).

Survival 2015	Estimate	SE	z-value	p-value
intercept for high-severity	26.88	7.11	3.78	0.0002 ***
intercept for low-severity	1.67	1.16	1.43	0.152
intercept for unburned	20.55	3758	0.01	0.995
individual size	-6.82	1.98	-3.43	0.0006 ***
canopy openness	-0.31	0.13	-2.38	0.0173 *
canopy openness x size	0.08	0.04	2.16	0.0310 *
Survival 2016	Estimate	SE	z-value	p-value
intercept for high-severity	-0.36	0.94	-0.38	0.70374
intercept for low-severity	2.68	1.14	2.36	0.01829 *
intercept for unburned	1.52	1.11	1.37	0.116
individual size	1.75	0.47	3.73	0.00019 ***
Survival 2017	Estimate	SE	z-value	p-value
intercept	-1.54	1.04	-1.49	0.137
individual size	2.15	0.44	4.85	0.0000013 ***
canopy openness	0.088	0.034	2.55	0.011 *
canopy openness by size	-0.027	0.014	-1.98	0.048 *
harvest	24.35	10.37	2.35	0.019 *
harvest by size	-7.33	2.81	-2.61	0.009 **

Coefficients calculated for individual size on a log scale. High-severity burn plots are the baseline for calculating other fire severity coefficients. In the 2015 survival model, standard errors are large for estimated coefficients for unburned plots because no individuals died in those plots. Due to the small number of individuals that died in 2015 and especially 2016, only interactions with size, but not fire severity were considered in the survival models in 2015, and the interaction of fire severity and size was not considered in 2016. Soil moisture measurements were also not included for these models as they were not taken in 2015 and were not taken in 2016 on a majority of the plants that died.

Table App.3.2-B: Coefficients for main effects and interactions in linear mixed-effects model for individual growth from one-two years post-fire.

Growth 2015-16	Estimate	SE	df	t-value	p-value
intercept for high-severity	0.83	0.16	845	5.32	0.0000 ***
intercept for low-severity	0.42	0.19	3	2.23	0.1113
intercept for unburned	-0.14	0.21	3	-0.68	0.5478
individual size for high-severity	0.78	0.05	845	15.22	0.0000 ***
individual size for low-severity	-0.12	0.06	845	-2.01	0.0444 *
individual size for unburned	<0.01	0.06	845	0.03	0.9798
Growth 2016-17	Estimate	SE	df	t-value	p-value
intercept for high-severity	0.50	0.15	1100	3.28	0.0011 **
intercept for low-severity	-0.35	0.14	4	-2.53	0.0645
intercept for unburned	-0.66	0.13	4	-4.87	0.0082 **
individual size	0.92	0.04	1100	22.80	0.0000 ***
early soil moisture for high-severity	0.023	0.008	1100	2.80	0.0051 **
early soil moisture for low-severity	0.015	0.005	1100	3.09	0.0020 **
early soil moisture for unburned	0.017	0.005	1100	3.38	0.0008 **
early soil moisture by size	-0.009	0.003	1100	-3.69	0.0002 ***

Coefficients calculated for individual size on a log scale. High-severity burn plots are the baseline for calculating other fire severity coefficients. In the growth 2016-2017 model I did not consider the interaction of fire severity with canopy openness because of insufficient overlap in canopy openness values between burned and unburned plots.

Table App.3.2-C: Coefficients for main effects and interactions in logistic mixed-effects model for flowering one, two and three years post-fire.

Flowering 2015	Estimate	SE	z-value	p-value
intercept for high-severity	-13.17	2.54	-5.20	2.0e-07 ***
intercept for low-severity	-2.57	0.75	-3.42	0.0006 ***
intercept for unburned	-3.52	0.77	-4.56	5.0e-06 ***
individual size	3.44	0.68	5.09	3.6e-07 ***
Flowering 2016	Estimate	SE	z-value	p-value
intercept for high-severity	-15.12	3.35	-4.51	6.8e-06 ***
intercept for low-severity	-1.78	0.69	-2.57	0.010 *
intercept for unburned	-24.67	30769.00	0.00	0.999
individual size	3.62	0.96	3.78	0.00016 ***
Flowering 2017	Estimate	SE	z-value	p-value
intercept	-20.59	2.78	-7.38	1.6e-13 ***
individual size	3.69	0.63	5.91	3.4e-09 ***
canopy openness	0.1016	0.0309	3.29	0.001 ***

Coefficients calculated for individual size on a log scale. High-severity burn plots are the baseline for calculating other fire severity coefficients. I did not explore interactions with fire severity in the flowering model in 2016 because only 14 individuals flowered. Late soil moisture was not used as a predictor of flowering, as it was measured after plants had flowered. Early soil moisture was not used in the 2015 model as it was not measured in 2015.

Table App.3.2-D: Coefficients for main effects and interactions in logistic mixed-effects model for vegetative reproduction two and three years post-fire.

Vegetative Reprod. 2016	Estimate	SE	z-value	p-value
intercept for high-severity	-5.38	1.79	-3.02	0.003 **
intercept for low-severity	-6.35	0.81	-2.34	0.019 *
intercept for unburned	0.94	0.84	0.35	0.730
individual size for high-severity	0.94	0.55	1.67	0.091 .
individual size for low-severity	2.02	0.81	2.51	0.012 *
individual size for unburned	-0.96	0.84	-1.15	0.250
recent flowering	3.10	0.49	6.32	2.5e-10 ***
Vegetative Reprod. 2017	Estimate	SE	z-value	p-value
intercept for high-severity	-9.51	1.26	-7.54	4.5e-14 ***
intercept for low-severity	-1.56	1.11	-1.41	0.1579
intercept for unburned	-5.23	1.35	-3.87	0.0001 **
individual size	2.68	0.33	8.24	< 2e-16 ***
harvest	0.79	0.27	2.87	0.0041 **
recent flowering for high-severity	8.90	2.04	4.37	1.26e-05 ***
recent flowering for low-severity	4.00	0.68	5.87	4.25e-09 ***
recent flowering for unburned	5.29	1.27	4.15	4.15e-05 ***
recent flowering x size	-2.77	0.62	-4.54	5.76e-06 ***

Coefficients calculated for individual size on a log scale. Recent flowering was used as a predictor in the vegetative reproduction models only and was defined in these models as any flowering in the current or past two years as plants were observed to produce clones over this timeframe. Late soil moisture was not used as a predictor of vegetative reproduction as it was measured after plants had vegetatively reproduced.

Table App.3.2-E: Coefficients for main effects and interactions in Conway-Maxwell-Poisson mixed-effects model for number of ramets per vegetatively reproducing individual

Number of new ramets	Estimate	SE	z-value	p-value
intercept	-0.64	0.38	-1.68	0.092
individual size	0.37	0.10	3.57	0.0004 ***
flowering (yes)	0.29	0.10	2.90	0.0037 **

Coefficients calculated for individual size on a log scale. Individual size refers to the mother individual size the year before clones appeared. Late soil moisture was not used as a predictor of the number of new ramets produced as it was measured after plants had vegetatively reproduced.

Table App.3.2-F: Pseudo R^2 (coefficients of determination) for vital rate models

Vital rate model	distribution	Random effects	Marginal $R^2_{GLMM(m)}$ (fixed effects)	Conditional $R^2_{GLMM(c)}$ (fixed + random effects)	R^2_{JB} (correlation fitted and observed)
Survival 2015	binomial	site/plot	0.7831	0.7980	0.354
Survival 2016	binomial	site/plot	0.0241	0.0241	0.052
Survival 2017	binomial	site/plot	0.0333	0.0383	0.290
Growth 2015-2016	Gaussian	site/plot	0.1769	0.1795	0.604
Growth 2016-2017	Gaussian	site/plot	0.3638	0.3836	0.702
Flowering 2015	binomial	site/plot	0.3651	0.5819	0.383
Flowering 2016	binomial	site/plot	---	---	0.282
Flowering 2017	binomial	site/plot	0.2305	0.2949	0.300
Vegetative reproduction 2016	binomial	site/plot	0.2009	0.2581	0.288
Vegetative reproduction 2017	binomial	site/plot	0.4498	0.5475	0.477
Number of vegetative ramets produced	Conway-Maxwell-Poisson	site/plot + year	0.0752 ±	0.2109±	0.313

± The MuMin package was not able to estimate pseudo R^2 for the Conway-Maxwell-Poisson and therefore these values are approximations using the Poisson distribution. The random effect “plot” is the same as the fixed effect “fire severity”, such that the random factor accounts for some variation by fire severity class. R^2_{GLMM} values were calculated with the MuMIn package in R, version 1.42.1. Marginal R^2_{GLMM} is variance explained by fixed effects, while conditional R^2_{GLMM} is the variance explained by fixed and random components of the models. I report trigamma estimations when available (number of number of vegetative ramets produced model), and delta estimations otherwise. The flowering 2016 model could not produce estimates with the MuMIn approach because there were not enough plants that flowered to estimate a null model. R^2_{JB} is the correlation between the fitted and observed values, as described by J. Byrnes here (written April 1st 2008): http://thread.gmane.org/gmane.comp.lang.r.lme4.devel/684

R code to implement is:

```
r2.corr.mer <- function(m) {
  lmfit <-  lm(model.response(model.frame(m)) ~ fitted(m))
  summary(lmfit)$r.squared
}
```

Random effects explained the largest portion of the variance in the flowering 2015 and vegetative production in 2017 models. In the flowering 2015 model, the variance was explained by random factors was almost entirely due to site, while for vegetative reproduction in 2017 it was due entirely to plots within sites.

Figure App.3.2-G: Seedling abundance and survival by site and fire-severity class

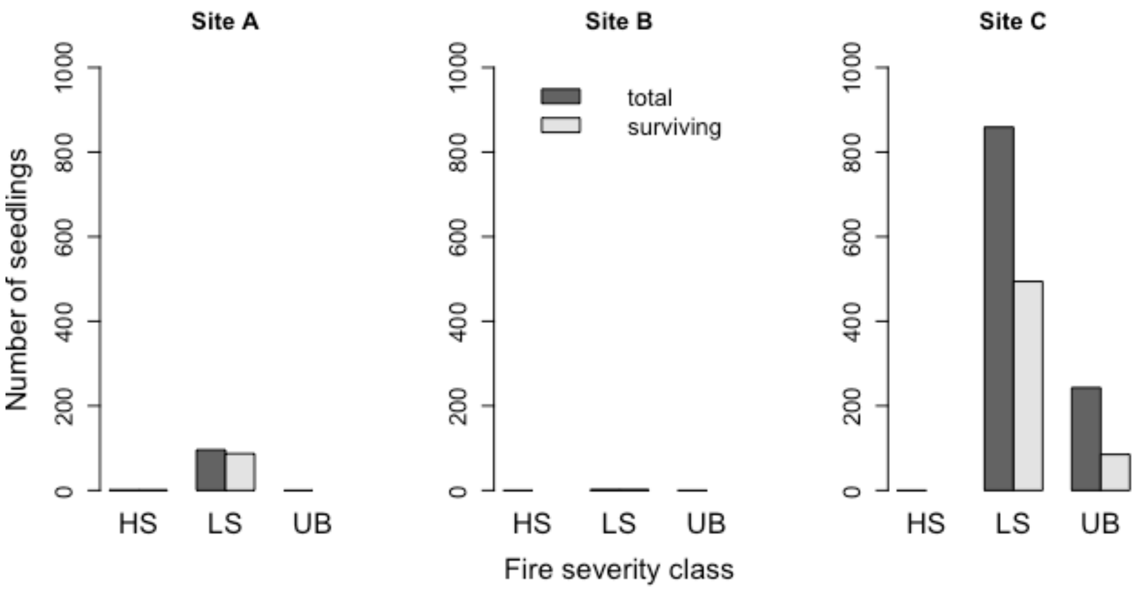


Figure App.3.2-G. Number of seedlings in 2016 (dark gray), and number of those surviving until 2017 (light gray) across three sites and across three fire-severity classes. HS= high-severity, LS= low-severity and UB = unburned.

Appendix 3.3. Additional contributions to Discussion

3.3-A: Discussion of mass flowering in beargrass

Flowering varied by site and year, and, though not always well captured in the dataset, mast or mass flowering was observed at sites B and C in 2015 and at site A in 2017. Mass flowering was not only at these specific sites in these years, but occurred across entire sections of the National Forest where those sites are located in each of those years. Neither the year the fire occurred nor the time of year that the fire burned can explain the mass flowering pattern I observed. Given these findings, it seems likely that mass flowering is controlled by climatic factors, mediated by individual age, fire history and light environment. Maule (1959) suggested that beargrass flower buds are formed the year before emergence, and that the growing season length and temperature the year prior could explain the amount of flowering. A study by Iler and Inouye (2013)(Iler & Inouye 2013) looked at mass flowering in a related species, *Veratrum tenuipetalum* (Melanthiaceae), and found that cool May-June temperatures two years prior were associated with larger flowering events, while length of growing season and precipitation, as well as climatic predictors one or three years prior were not associated with flowering. In their study, they hypothesized that individuals preform their flower buds 2 or 3 years prior to flowering, based on the timing of leaf formation. Future beargrass studies related to mass flowering, may want to capture soil moisture, temperature and precipitation over at least a three-year period prior to each mass flowering event. While soil temperature was mentioned by Maule as a possible factor controlling flowering, I was not able to include that measurement in this study.

3.3-B: Discussion of vegetative reproduction

The proportion of individuals that vegetatively reproduced, like flowering, was higher in 2017 compared to 2016, however, unlike flowering, the proportion of individuals vegetatively reproducing in 2017 was more evenly spread across sites, rather than being concentrated in particular sites that mass flowered. This suggests that sexual and vegetative reproduction are controlled by a somewhat different mix of drivers over multi-year timescales. Vegetative reproduction in high severity burn plots occurred, on average, at a smaller individual size and was less dependent on size and more dependent on light than in low severity plots. Higher nutrient additions or a greater reduction in competition (Xie *et al.* 2014) in the high severity plots may have allowed plants to reach a threshold for vegetative reproduction at a smaller size. Alternatively, aboveground basal diameter measurement after fire may have been a poor reflection of belowground resources available for reproduction (Hartnett 1987).

3.3-C Reasons for lack of seedlings emergence in high severity burn plots

High severity fire could have reduced microbial and fungal soil communities that promote seedling germination (Certini 2005), or a high herbivory rate on inflorescences that I observed in high severity burn plots restricted seed dispersal. Flowering stalks in high severity burn plots may have been over-selected by deer and elk due to the known pattern of fire encouraging ungulate browsing (Fuhlendorf *et al.* 2008), and possibly due in part to a higher nutritional value (Canon, Urness & DeByle 1987). Another contributing factor to the lack of seedlings in high severity plots could be changes in microhabitat conditions that could affect seedling establishment and survival, such as the lack of moss cover, which may have increased thermal stress. High severity plots had the lowest moss cover in the study.

Appendix 3.4: Observed soil moisture and canopy openness values by fire severity

Soil moisture was consistently lower in the late growing season compared to the early growing season across all plot types. Soil moisture was also consistently lowest in the high severity burn plots, and highest in the low severity plots, with unburned plots having values intermediate of the two burn severities. Average soil moisture was generally lower in 2017 compared to 2016. Canopy openness values were highest in the high severity plots, followed somewhat closely by the low severity plots. Unburned plots had much lower canopy openness and less than 10% overlap in canopy openness range with low severity plots.

Table App.3.4. Mean, standard deviation, sample size and range of soil moisture and canopy openness values across fire severities two and three-years post-fire.

Abiotic factor and year	Unburned plots	Low severity plots	High severity plots
Early season soil moisture 2016	19.5% (5.6%) n=592 Range: 7.0-31.2%	22.7% (4.6%) n=1378 Range: 7.6-35.7%	15.8% (4.3%) n=382 Range: 4.6-26.7%
Late season soil moisture 2016	9.8% (5.9%) n=596 Range: 0.6-25.3%	15.8% (5.7%) n=1403 Range: 1.3-30.2%	9.6% (4.0%) n=383 Range: 0.3-30.1%
Early season soil moisture 2017	15.0% (6.2%) n=611 Range: 0.2-31.8%	20.2% (6.1%) n=1651 Range: 1.9-34.2%	12.9% (5.4%) n=661 Range: 3.2-28.3%
Late season soil moisture 2017	5.0% (3.1%) n=612 Range: 0.1-20.4%	5.9% (3.2%) n=1649 Range: 0-18.0%	3.3% (1.7%) n=664 Range: 0.2-12.2%
Canopy openness All years	21.5% (5.0%) n=614 Range: 8.7-32.7%	40.3% (11.6%) n=1654 Range: 25.7-69.5%	47.8% (11.8%) n=614 Range: 10.0-76.1%

Appendix 3.5. Relationships soil moisture to season and time of day

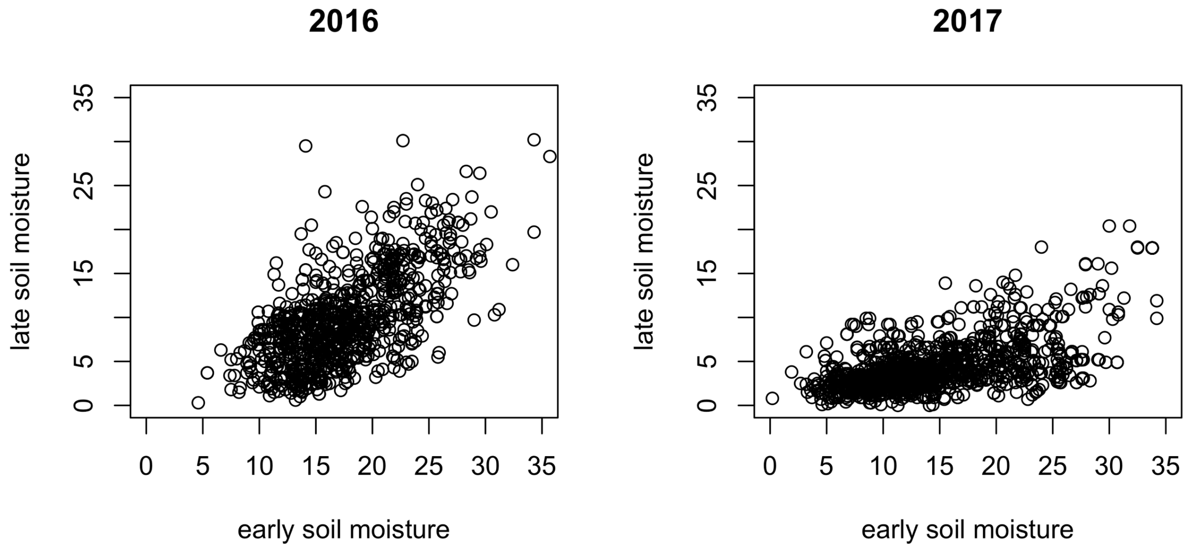


Figure App.3.5-A. Percent volumetric early summer season (late May/early June) and late summer season (late July/early August) soil moisture (top 12 cm) in 2016 and 2017. Pearson correlation coefficients are 0.64 (2016) and 0.54 (2017). Data points in 2016 are the average of three soil moisture readings evenly spaced around each individual, while those in 2017 are a single reading per individual.

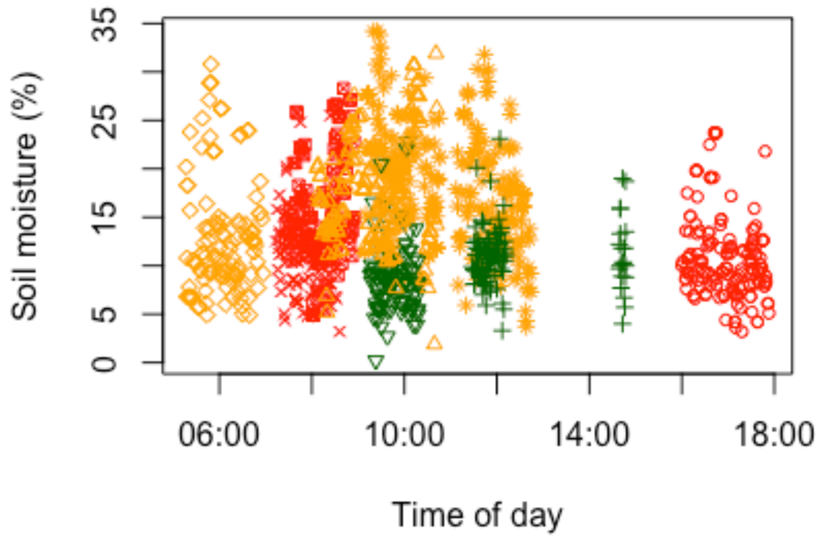


Figure App.3.5-B. Soil moisture by time of day in June of 2017. Red points are high severity, orange are low severity and green are unburned plots. Symbols represent different plots.

Appendix 4.1. Integral Projection Models

Regression models and fire severities used to build nine IPMs that were utilized in the fire simulations. Samples sizes are for surv= survival, grw= growth, vrep= vegetative reproduction, srep= sexual reproduction, ncln= number of clones, ncap= number of seed capsules. Data is from plots across three sites that all experiences wildfire in 2014. Samples sizes increase as more individuals are recruited into the plots.

IPM	Asymptotic growth rate (λ)	Regression sample sizes
2015, high severity fire	0.895	surv: 929, grw: 848, vrep: 876, srep: 790, ncln: 216, ncap: 61
2015, low severity fire	1.105	as above
2015, unburned	1.072	as above
2016, high severity fire	0.989	surv: 858, grw: 848, vrep: 876, srep: 886, ncln: 216, ncap: 61
2016, low severity fire	1.246	as above
2016, unburned	0.997	as above
2017, high severity fire	1.115	surv: 1130, grw: 1114, vrep: 1127, srep: 930, ncln: 216, ncap: 61
2017, low severity fire	1.157	as above
2017, unburned	0.924	as above

Appendix 4.2: Seed germination and seed bank study

In order to determine the survival and germination rate of seeds, and to explore the possibility that beargrass has a seed bank, seeds were collected from individuals in two of the three sites (site A could not be included because plants did not flower in the first year). Seed capsules open when seed is mature in late summer (Vance *et al.* 2001) and mature seed is tan in color (Wick, Evans & Luna 2008). At sites B and C, one inflorescence on 20 separate individuals (genets) were selected from two different locations outside the fire. Due to low numbers of plants flowering in the surrounding unburned area at Site C, seeds were also collected from plants flowering within the fire (but not within study plots). Care was taken to carry out seed collection at locations separate from the study plots and on plants that were each separated by at least 5 meters. Twenty seeds were collected per individual by shaking mature, beige-colored seed out of dehisced (open) seed capsules. These 20 seeds were separated into two mesh bags for a total of 10 seeds per bag and two bags per plant (400 total seeds). These nylon mesh bags were buried separately at 6 cm depth (Hooftman *et al.* 2015). At each site, seed from unburned areas was buried at a single site that was unburned. At site A, seed from the burned area was buried at a burned location. In years two and three, half of the bags (one from each plant) were dug up and assessed for germination immediately in the field and then again under dissecting microscope. Germination was defined as emergence of the radicle from the seed. For those seeds that did not germinate, seed viability was tested using in 2016 (year two) using tetrazolium staining at the Oregon State Seed Lab, and in 2017 (year three) through a germination study following published procedures for beargrass (Smart & Minore 1977) at the Rae Selling Berry Seed Bank & Plant Conservation Program.

Of the seeds buried in late summer of 2015 and uncovered in late summer of 2016, an average of 27.2% of the seeds per bag germinated (stdev of 27.8%, n=27 bags, each with ~10 seeds each from a separate plant). Germination rate of a given bag in the field ranged from 0-71%. Viability analysis in 2016 through tetrazolium staining indicated that only an additional 9.2% of the remaining, non-germinated seeds were viable. In late summer 2017, the remaining seed bags were dug up and had an average germination rate of 41.7% per bag (stdev of 28.4%, n=21 bags, each with ~10 seeds each from a separate plant) over two years. Germination rate of a given bag in the field in 2017 ranged from 0-100%. Some of the seeds clearly germinated in year two (green shoots still present), indicating that beargrass has a seed bank and that seeds can persist for at least 21 months underground before germinating. Seeds that did not germinate in the field by 2017, also did not germinate in the lab. For both years, it is possible that warm seed storage temperatures lowered viability and germination. For example, the seeds may have gone back into dormancy by late summer or after experiencing warm temperatures when they were taken from Mount Hood down to Portland, OR where they were kept for several weeks before germination trials could be initiated.

Appendix 4.3. Stochastic population growth rates and confidence intervals

Fire-harvest scenario	Mean	Standard error	Confidence interval - lower	Confidence interval - upper
Business as usual	0.9907	0.0006446	0.9895	0.9920
Business as usual with leaf harvest	0.9922	0.0006817	0.9908	0.9935
Prescribed or cultural fire	1.0158	0.0007721	1.0142	1.0173
Prescribed or cultural fire with leaf harvest	1.0158	0.0007559	1.0143	1.0173
No fire	0.9904	0.0006716	0.9890	0.9917
No fire with leaf harvest	0.9893	0.0006530	0.9880	0.9906

Appendix 4.4: Stochastic population growth rate at varying fire return intervals

Fire-harvest scenario	Fire return interval	λ_s	95% CI
Business as usual (BAU)	180	0.9907	0.9895- 0.9920
BAU	100	0.9929	0.9916- 0.9942
BAU	80	0.9938	0.9925 - 0.9951
BAU	60	0.9958	0.9945 - 0.9971
BAU	40	0.9980	0.9964 – 0.9995
BAU	20	1.0080	1.0056 - 1.0103
BAU	10	1.0298	1.0268 – 1.0329
BAU	2	1.0583	1.0543 – 1.0624

Fire-harvest scenario	Fire return interval	λ_s	95% CI
Prescribed or cultural fire (PRCUF)	100	0.9975	0.9964 – 0.9987
PRCUF	80	1.0035	1.0021 – 1.0049
PRCUF	60	1.0017	1.0004 – 1.0030
PRCUF	40	1.0063	1.0047 – 1.0078
PRCUF	20	1.0158	1.0142– 1.0173
PRCUF	10	1.0410	1.0392 - 1.0428
PRCUF	2	1.1000	1.0968 – 1.1030

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